Fecal Coliform TMDL for Dry River, Rockingham County, Virginia

Revised Final Report

Submitted by

Virginia Department of Environmental Quality
Virginia Department of Conservation and Recreation

Prepared by

Virginia Tech
Department of Biological Systems Engineering
and
Department of Biology

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Note: This revised report varies from the report published in December 2000 because it now includes the modifications described in the addendum.

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1. EXECUTIVE SUMMARY

1.1. Background

The Dry River watershed is located in the southwestern portion of Rockingham County, Virginia, west of the City of Harrisonburg. The headwaters are in the George Washington National Forest in the mountains to the west, with the river flowing in a southeasterly direction to its confluence with North River just west of Bridgewater. North River is a tributary of the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005), which in turn is a tributary of the Potomac River, which discharges into the Chesapeake Bay.

From its confluence with North River, the entire Dry River drainage is divided into three watersheds in the Virginia hydrologic unit coding system. The predominantly forested area northwest of Rawley Springs is referred to as the upper Dry River watershed (VAV-B20R) and is approximately 46,741 acres. From Rawley Springs downstream to the outlet is the lower Dry River watershed (VAV-B21R), approximately 10,051 acres in size and predominantly agricultural. The Muddy Creek watershed (VAV-B22R, 20,025 acres) is a tributary to the lower Dry River segment, with its confluence located about 2.64 miles upstream of North River. This report and study focuses on the lower Dry River watershed, and specifically, the 6.47mile segment from the Rt. 613 bridge at Lilly downstream to the confluence with North River.

Water quality samples collected from Dry River over five years (September 1993 – December 1998), had fecal coliform concentrations that violated the instantaneous criterion of the water quality standard in 32% of those samples. The instantaneous criterion specifies that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the high frequency of water quality violations, Dry River was placed on Virginia's 1998 303(d) list of impaired waterbodies for fecal coliform (USEPA, 1998a). The listed impaired segment is the 6.47 miles between the Rt. 613 bridge at Lilly and the confluence with North River. VADCR has assessed this watershed as having a high potential for nonpoint source pollution from agricultural lands. Muddy Creek was also listed in the 1998 303(d) list as being impaired with respect to fecal coliform and has an approved fecal coliform TMDL as of September 1999.

As a result of the water quality impairment, Dry River was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and included on the 1998 303(d) list (USEPA, 1998a,b). In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) was developed, taking into account all sources of fecal coliform and a margin of safety (MOS). Upon implementation, the TMDL for Dry River ensures that the water quality standard for fecal coliform will be in compliance with the geometric criterion. The geometric criterion specifies that the 30-day geometric mean concentration of fecal coliform shall not exceed 200 cfu/100mL.

1.2. Sources of Fecal Coliform

Fecal coliform in the impaired segment of Dry River originate from agricultural, residential, and wildlife nonpoint sources, and from inflow from Muddy Creek. There are no permitted point sources discharging to Dry River. A TMDL plan developed for Muddy Creek (Muddy Creek TMDL Establishment Workgroup, 1999) provides the basis for an implementation plan to ensure that outflow from Muddy Creek will meet the state's water quality standard in the future. Since a TMDL plan has already been developed and approved for Muddy Creek, time series of flow and fecal coliform concentration developed as part of that TMDL were used to characterize the inflows from Muddy Creek to Dry River. For the modeling analysis in this study, the daily runoff and fecal coliform loads for existing conditions and for the approved Muddy Creek TMDL allocation were considered as direct (point source) input to Dry River. Thus, no additional consideration was given to sources in the Muddy Creek watershed, and further mention of the Dry River watershed in this report refers specifically to the upper and lower Dry River watersheds (VAV-B20R, VAV-B21R) and does not include the Muddy Creek watershed.

The lower Dry River watershed has a high density of dairy and poultry operations, and some beef cattle. Animal waste directly deposited or spread on the pastures and cropland is subject to washoff from rainstorms, while cattle access to streams results in direct fecal coliform loading. Similarly, wildlife sources contribute to fecal loads through direct deposition in the stream as well as surface loads that are subject to washoff. Non-agricultural nonpoint sources of fecal coliform loadings include failing septic systems and pet waste which are subject to washoff. No direct discharge of household wastewater (straight pipes) was identified for this watershed. Fecal coliform loads were estimated on a monthly basis to account for seasonal variability in production and practices, considering factors such as the fraction of time cattle are in confinement, time spent in streams, and manure storage and spreading schedules. For the upper Dry River watershed, wildlife was the only source of fecal coliform considered.

1.3. Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Dry River watershed. The BASINS (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 2.0 interface was used to facilitate use of HSPF. Given the difference in land-use, the hydrology of the upper and lower Dry River watersheds were modeled separately. The forested upper Dry River watershed was divided into five subwatersheds. To identify localized sources of fecal coliform, the lower Dry River watershed (17.7% of the total area), was divided into six subwatersheds.

Due to the short period of flow record available for Dry River, the hydrology component of HSPF was calibrated for Linville Creek, a tributary of North Fork of the Shenandoah River, which has a long period of record. The HSPF was calibrated for Linville Creek using data from a 4.5-year period. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions as well as seasonal variations. The calibrated HSPF data set was validated on a separate period of record for Linville Creek (5 years) and Muddy Creek (3+ years), a tributary of Dry River. In the first stage, the hydrology of the upper Dry River was simulated. In the next stage, time series of flows from the upper Dry River and Muddy Creek were input as point sources to simulate the hydrology of the lower Dry River. The calibrated HSPF model adequately simulated the hydrology of the Dry River watershed.

The water quality component of HSPF was calibrated using three years (September 1993 – July 1996) of fecal coliform data collected in the watershed. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. Assuming a fecal coliform concentration of 30 cfu/100 mL applicable to pristine areas (Muddy Creek TMDL Establishment Workgroup, 1999), time series of fecal coliform loading from the upper Dry River watershed was used as input to simulate the water quality of the lower Dry River. Similarly, time series of fecal coliform loading from Muddy Creek was also provided as input to the model. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate of fecal coliform in the watershed.

1.4. Existing Conditions

Monthly fecal coliform loadings to different land-use categories were calculated for each subwatershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off in storage prior to land application. Fecal coliform die-off on the land surface was considered, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal fecal coliform loading in the stream by cattle was calculated for pastures adjacent to streams. Fecal coliform loading due to direct discharge of milking parlor washoff in the stream was based on the location of the dairy operation with respect to the stream and number of milk cows in the dairy operation. Fecal coliform loadings in the stream or on land by wildlife were estimated for deer, raccoons, muskrats, and ducks. Fecal coliform loading to land from failing septic systems was estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered.

For the representative hydrologic period of September 1993 through July 1996, HSPF was calibrated to the existing conditions pertaining to fecal coliform loading. Nearly 61% of the mean daily fecal coliform concentration comes from Muddy Creek inflow and 36% from cattle directly depositing in the stream. The remaining 3% of the mean daily fecal coliform concentration comes from upland areas, milking parlor wash-water, and wildlife defecating in the stream. Fecal coliform loadings were significantly higher during base flow periods and during summer. While base flow conditions allowed for little fecal coliform dilution, cattle spent more time in the water during summer, thereby increasing direct fecal coliform deposition in the stream. Results indicated frequent violations of the 200 cfu/100 mL geometric mean standard for the watershed.

1.5. Margin of Safety

While developing allocation scenarios to implement the TMDL, an explicit margin of safety (MOS) of 5% was used. Hence, the maximum 30-day geometric mean target for the allocation scenario was 190 cfu/100 mL, 5% below the standard (200 cfu/100 mL). It is expected that a MOS of 5% will account for any uncertainty involved in the accuracy of the input data used in the model.

1.6. Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet the 30-day geometric mean criterion (200 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

Table 1.1. Allocation scenarios for Dry River watershed

Scenario Number	Percent reduction in loading from existing condition				
	Direct wildlife deposits	Direct cattle deposits	NPS from land segments	Milking parlor wash-off	Percentage of days with 30-day GM > 190 cfu/100mL
1	0	50	0	100	29.3
2	0	75	0	100	4.9
3	**0**	**84**	**0**	**100**	**0.0**
4	0	75	50	100	4.0

The scenarios listed in Table 1.1 assume full implementation of the Muddy Creek TMDL and a mean daily fecal coliform concentration of 30 cfu/100mL from the upper Dry River watershed. Scenario 3 meets the TMDL allocation requirement of no violations of the 190 cfu/100mL 30-day geometric mean goal (Table 1.1). Scenario 3 requires an 84% reduction in direct fecal coliform loading to the stream from cattle and no reduction in nonpoint sources of fecal coliform. Scenarios 1 through 3 (Table 1.1) indicate the significance of cattle in streams as a source of fecal coliform loading. Hence, emphasis should be placed on reducing direct deposits from cattle in the streams. The required load reductions for the TMDL allocation are listed in Tables 1.2 and 1.3 for nonpoint and direct nonpoint sources, respectively. The 30-day geometric mean fecal coliform concentrations resulting from Scenario 3, as well as the existing conditions, are presented graphically in Figure 1.1.

Table 1.2. Annual nonpoint source loads under existing conditions and corresponding reductions for TMDL allocation scenario 3.

Land-use Category	Existing conditions		Allocation scenario	
	Existing load ($\times 10^{12}$ cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	67.5	20.2	67.5	0.0
Pasture 1	119.9	35.9	119.9	0.0
Pasture 2	14.7	4.4	14.7	0.0
Pasture 3	111.7	33.5	111.7	0.0
Loafing Lots	2.1	0.6	2.1	0.0
Rural Residential	8.6	2.6	8.6	0.0
Farmstead	5.3	1.6	5.3	0.0
Forest	3.9	1.2	3.9	0.0
Total[a]	333.7	100.0	333.7	0.0

[a] There is no loading from urban residential land-use type

Table 1.3. Annual direct nonpoint source load reductions for TMDL allocation Scenario 3.

Source	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	182.4	98.1	29.2	84.0
Wildlife in Streams	2.4	1.3	2.4	0.0
Milking parlor wash-off	1.1	0.6	0	100.0
Total	185.9	100.0	31.6	83.0

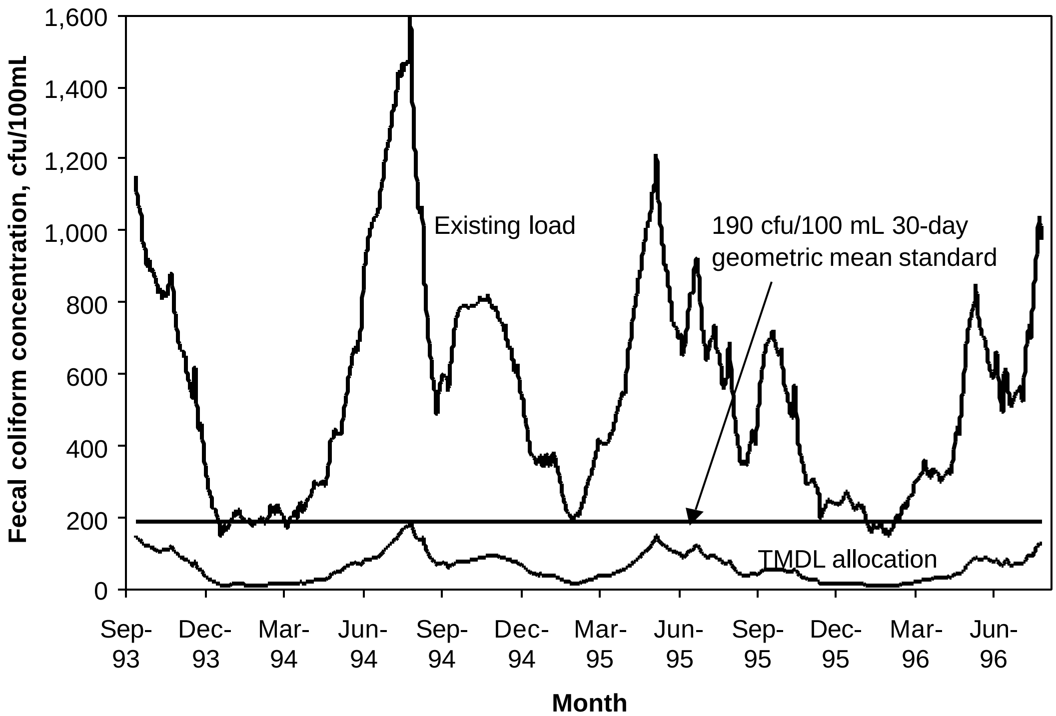

Figure 1.1. Successful TMDL allocation, 190 cfu/100 mL 30-day geometric mean goal, and existing conditions for Dry River (Scenario 3, Table 1.1).

For the selected scenario (Scenario 3), load allocations were calculated using the following equation.

$$\mathrm{TMDL} = \Sigma \mathrm{WLA} + \Sigma \mathrm{LA} + \mathrm{MOS} \quad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, 5% of TMDL.

Since there are no point sources of fecal coliform in the lower Dry River watershed, the proposed scenario requires load allocations for only the nonpoint source contributions. Based on reductions required from existing conditions and fecal coliform loadings given in Tables 1.2 and 1.3, the summary of fecal coliform TMDL is given in Table 1.4.

Table 1.4. Annual fecal coliform loadings (cfu/year) used for developing the fecal coliform TMDL for the Dry River

Parameter	S WLA	S LA	MOS[a]	TMDL
Muddy Creek[b]	0.30×10^{12}	8.35×10^{12}	0.46×10^{12}	9.11×10^{12}
upper Dry River	0	0.88×10^{12}	0.05×10^{12}	0.93×10^{12}
lower Dry River[c]	0	365.30×10^{12}	19.23×10^{12}	384.53×10^{12}
Total	0.30×10^{12}	374.53×10^{12}	19.74×10^{12}	394.57×10^{12}

[a] Five percent of TMDL
[b] After TMDL implementation (Muddy Creek TMDL Establishment Workgroup, 1999)
[c] Excluding Muddy Creek loading

The TMDL allocation requires 84% reduction of fecal coliform from direct deposits by cattle in the streams and elimination of the direct pipe discharging milking parlor wash-off to the stream. However, no reductions from nonpoint sources or from wildlife depositing in streams are required.

1.7. Phase 1 Implementation

An alternative scenario was evaluated that requires less drastic changes in management practices and achieves smaller reduction in fecal coliform concentration in the stream. The implementation of such a transitional scenario, or Phase 1 implementation, will allow for an evaluation of the modeling assumptions and the effectiveness of management practices and for the collection of additional data, with the objective of enhancing model results, if necessary. Phase 1 implementation was developed for a maximum of 10% violations of the instantaneous criterion (1,000 cfu/100 mL) based on monthly sampling frequency Phase 1 implementation requires a 28% reduction in direct fecal coliform loading by cattle into the stream and elimination of direct discharge of wash-water from milking parlors into streams. No reduction in fecal coliform loadings from the upland areas or reductions from Muddy Creek are required during this phase. The Phase I implementation scenario accounts for a monitoring frequency of once per month, which ties the implementation to Muddy Creek, a significant contributor to the Dry River.

1.8. Reasonable Assurance of Implementation

A phased TMDL implementation plan has been developed that allows for the interim evaluation of the effectiveness of the proposed TMDL implementation while progressing toward compliance with Virginia's water quality standard. Phase 1 implementation allows for the evaluation of the effectiveness of management practices through stream monitoring on a monthly basis. Also, data collection during this phase allows for the quantification of uncertainties that affect TMDL development. By accounting for such uncertainties, the TMDL can be improved for the final implementation phase that requires full compliance with the 200 cfu/100 mL geometric mean water quality standard.

1.9. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Three public meetings were organized for this purpose. The first public meeting was organized on December 9, 1999, to inform the stakeholders of the TMDL development process and to obtain feedback on animal numbers in the watershed. Results of the hydrologic calibration and animal population, and fecal production estimates were discussed in the second public meeting on January 20, 2000. The draft TMDL report was presented at the third public meeting held on March 28, 2000.

2. INTRODUCTION

2.1. Background

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) (USEPA, 1998a) require states to identify waterbodies that violate state water quality standards and to develop Total Daily Maximum Loads (TMDLs) for such waterbodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a waterbody, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of waterbodies. The fecal coliform bacterium is found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though fecal coliform is not pathogenic, its presence in water indicates the potential for contamination by fecal material. Since fecal material can contain other pathogenic organisms, waterbodies with high fecal coliform counts are likely to contain higher concentrations of pathogenic bacteria. For contact recreational uses, e.g., boating and swimming, health risk increases with fecal coliform count in the waterbody. If the fecal coliform concentration in a waterbody exceeds state water quality standards, the waterbody is listed for violation of the state fecal coliform standard for contact recreational uses.

The Virginia Department of Environmental Quality (VADEQ) has identified Dry River as being impaired by fecal coliform for a stream length of 6.47 miles, beginning at the Rt. 613 bridge at Lilly and continuing downstream to its confluence with North River. The Dry River drainage is located in Rockingham County, Virginia, about 5 miles west of Harrisonburg (Figure 2.1). The headwaters are in the George Washington National Forest in the mountains to the west, with the river flowing in a southeasterly direction to its confluence with North River, just west of Bridgewater. North River is a tributary of the

South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005), which in turn is a tributary of the Potomac River which discharges into the Chesapeake Bay.

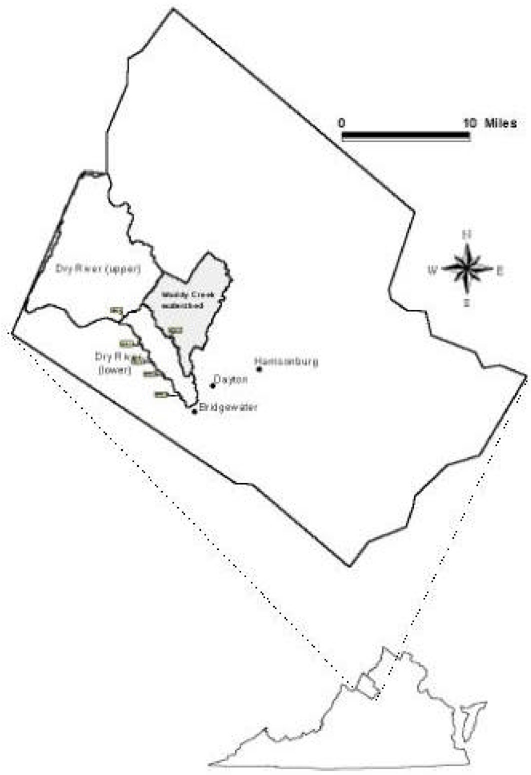

Figure 2.1. Location of Dry River watershed

From its confluence with North River, the entire Dry River drainage is divided into three watersheds in the Virginia hydrologic units coding system. The predominantly forested area northwest of Rawley Springs is referred to as the upper Dry River watershed (VAV-B20R) and is approximately 46,741 acres (Figure 2.1). From this point downstream to the outlet is the lower Dry River watershed (VAV-B21R) (Figure 2.1), approximately 10,051 acres and predominantly in agricultural land use. The Muddy Creek watershed (VAV-B22R, 20,025 acres) is a tributary to the lower Dry River segment, with its confluence about 2.64 miles upstream of North River. Since the entire length of impairment is confined to the lower Dry River watershed, the TMDL was targeted for this watershed with a completion date during the 1998-2000 period.

A fecal coliform TMDL was developed for Muddy Creek (VAV-B22R) by the Muddy Creek TMDL Establishment Workgroup (1999). The Muddy Creek TMDL required 57 and 99% reductions in fecal coliform loading from nonpoint sources (upland areas) and direct nonpoint sources (in-stream sources), respectively. Under existing conditions, the predominant source of fecal coliform in Muddy Creek was cattle in the streams, accounting for more than 86% of the total fecal coliform loading (Muddy Creek TMDL Establishment Workgroup, 1999).

In addition to Muddy Creek, the Dry River has another important tributary in the lower Dry River watershed, Honey Run. Even though Honey Run is ephemeral, it could have a significant impact on the fecal coliform loading to the stream. A reconnaissance of the watershed by the Virginia Tech team revealed that cows graze in the dry streambed of Honey Run. It is likely that during significant rainfall events, a portion of the fecal coliform deposited in the streambed would be transported to the Dry River.

2.2. Applicable Water Quality Standards and Critical Conditions

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standards for contact recreational use, VADEQ specifies the following criteria (9 VAC 25-260-170):

1. Instantaneous criterion: Fecal coliform count shall not exceed 1,000 colony forming units (cfu) per 100 mL at any time.
2. Geometric mean criterion: The geometric mean count of fecal coliform of two or more water quality samples taken within a 30-day period shall not exceed 200 cfu/100 mL.

If the waterbody exceeds either criterion more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or dataset (9 VAC 25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric criterion is applied. For the Dry River, the TMDL is required to meet the geometric mean criterion since the computer simulation gives daily fecal coliform concentrations, analogous to daily sample collection. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

2.3. The Water Quality Problem

The Dry River watershed supports a large livestock population comprised of mainly cattle and poultry; most of the animal waste generated is applied to agricultural lands. The Virginia Department of Conservation and Recreation (VADCR) has assessed this watershed as having a high potential for nonpoint source (NPS) pollution from agricultural lands. Of the 64 monthly water quality samples collected by VADEQ from September 1993 to December 1998 at the outlet of the watershed, 32% of the samples exceeded the instantaneous mean criterion of 1,000 cfu/100 mL. Consequently, the impaired segment of the Dry River was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1998 305(b) report and included on the 1998 303(d) list (USEPA, 1998a, b).

2.4. Objective

The objective of the project was to develop a TMDL for Dry River that accounts for both point and nonpoint source pollutant loadings and incorporates a margin of safety to meet state fecal coliform standards for non-shellfish waters with respect to the geometric criterion. The following tasks were performed to achieve the project objective.

- Task 1. Identified potential fecal coliform sources, including background sources, and estimated the magnitude of each source in cooperation with stakeholders;
- Task 2. Quantified fecal coliform production from each source;
- Task 3. Simulated attenuation of fecal coliform during transport from deposited locations to water bodies;
- Task 4. Accounted for variations in precipitation, hydrology, and land-use in simulating fecal coliform deposition in streams;
- Task 5. Estimated fecal coliform concentrations in waterbodies under present conditions;

Task 6. Explored multiple scenarios to reduce fecal coliform concentrations to meet the geometric criterion;

Task 7. Selected a TMDL that can be realistically implemented and is socially acceptable; and

Task 8. Incorporated a margin of safety into the TMDL.

3. WATERSHED CHARACTERIZATION

3.1. Water Resources

The Dry River watershed has 42.8 miles of streams. Muddy Creek discharges into the Dry River about 2.64 miles upstream from the watershed outlet. About 0.4 miles downstream from the confluence of Dry River and Muddy Creek, Honey Run discharges into the Dry River. Downstream from the confluence with Muddy Creek, Dry River is perennial while it is ephemeral in the upper reaches. Honey Run is also ephemeral. During September 1993 through September 1996, measured discharge at the watershed outlet ranged from 1170.00 cfs to 7.00 cfs, with a mean value of 147.76 cfs (VADEQ, 1997). Aquifers in the upper part of the watershed are overlain by shale, limestone, and dolomite and, due to a land cover consisting primarily of forest, have low potential for groundwater pollution (VWCB, 1985). Aquifers in the lower part of the watershed are overlain by limestone and dolomite (VWCB, 1985). Because of agricultural land use, potential for groundwater pollution in the lower part of the watershed, especially around sinkholes and in areas with thin soils, could be very high (VWCB, 1985). Depth to the water table ranges from 1.5 ft to more than 6 ft in the watershed (SCS, 1985). Higher water tables (1.5 - 3 ft) are due to the existence of perched aquifers during December through April (SCS, 1985).

3.2. Soils and Geology

The three soil associations found in the watershed, Lehew-Dekalb-Calvin, Monongahela-Unison-Cotaco, and Frederick-Lodi-Rock outcrop are characterized as follows (SCS, 1985). Lehew-Dekalb-Calvin (very stony loam and sandy loam) soils are found in the upper part of the watershed, away from the Dry River floodplain. Lehew-Dekalb-Calvin soils are moderately deep, well drained, and have loamy subsoil. Monongahela-Unison-Cotaco (cobbly fine sandy loam and fine sandy loam) soils are found on terraces adjacent to streams and rivers. Monongahela-Unison-Cotaco soils are deep, moderately well drained to well drained, and have loamy or clayey subsoil. Frederick-Lodi-Rock outcrop (silty loam) soils occur away from the floodplain in the lower part of the watershed. Frederick-Lodi-Rock outcrop soils are deep and well drained with clayey subsoil and areas of rock outcrop.

3.3. Climate

The climate of the watershed is characterized based on the meteorological observations made by the National Weather Service's cooperative observer at Dale Enterprise. Dale Enterprise is located 5.7 miles northwest of the watershed. Average annual precipitation is 33.6 in. with 59% of the precipitation occurring during the crop growing season (May-October) (SERCC, 2000). Average annual snowfall is 26.5 in. with the highest snowfall occurring during February (SERCC, 2000). Average annual daily temperature is 53.3°F. The highest average daily temperature of 73.6°F occurs in July while the lowest average daily temperature of 31.0°F occurs in January (SERCC, 2000).

3.4. Land-use

Using 1995 aerial photographs, VADCR identified 30 land-use types in the watershed. The land-use was verified and updated in October 1999 by Virginia Tech. The 30 land-use types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 3.1).

The lower Dry River watershed, where the entire impaired stream length is located, was divided into six subwatersheds (DRR-A to DRR-F) to spatially analyze waste or fecal coliform distribution (Figure 3.1). Given that the upper Dry River is not impaired and is entirely forested, it is represented in Table 3.1 as a single subwatershed (DRR-G). However, for the purpose of modeling, DRR-G was divided into five subwatersheds (Chapter 5). Land-use distribution in the subwatersheds and the Dry River watershed is presented in Table 3.2.

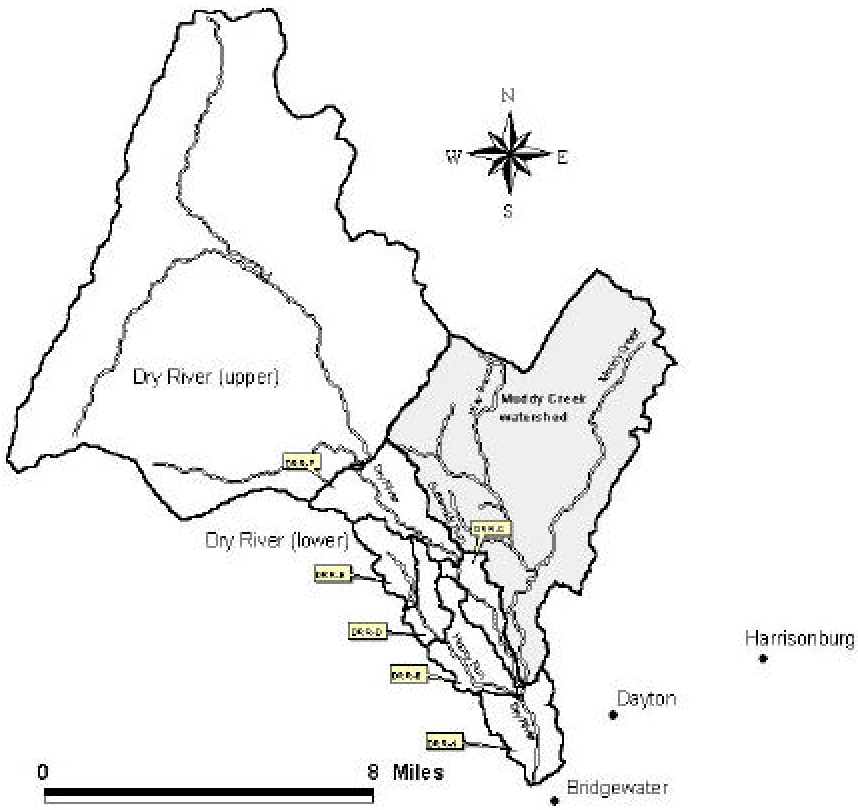

Figure 3.1. Dry River subwatersheds and stream network

Table 3.1. Consolidation of VADCR land-use categories for Dry River watershed

TMDL Land-use Categories	Pervious/Impervious[a] (Percentage)	VADCR Land-use Categories (Class No.)
Cropland	Pervious (100%)	Row Crops (2110) Gullied Row Crops (2111) Row Crops Stripped (2113) Rotational Hay (2114) Orchard (221)
Pasture 1	Pervious (100%)	Improved Pasture/Hayland (2122) Pasture (2121)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123) Grazed Woodland (43)
Pasture 3	Pervious (100%)	Overgrazed Pasture (2124)
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facility (813) Beef Farm (815) Large Individual Dairy Waste Facility (8)
Rural Residential	Pervious (72%) Impervious (28%)	Built-Up > 50% Porous (12) Rural Residential (14) Wooded Residential (44)
Urban Residential	Pervious (75%) Impervious (25%)	Built-Up < 50% Porous (11) Sewered Residential (16) Unclassified (999) Transitional and Disturbed Sites (7)
Loafing Lot	Pervious (100%)	Dairy Loafing Lots (2312) Unhoused Poultry (2322)
Forest	Pervious (100%)	Forest (40) Recently Harvested Woodland-Clear Cut (41) Recently Harvested Woodland-Not Clear Cut (42) Unmanaged Grass and Shrubs (3) Water (5) Nurseries and Christmas Tree Farms (222)

[a] Percent perviousness/imperviousness information was used in modeling (described in Chapter 5)

Table 3.2. Land-use distribution in the subwatersheds (acres)

Land-use	Subwatersheds							Total[a]	
	DRR-A	DRR-B	DRR-C	DRR-D	DRR-E	DRR-F	DRR-G[b]	Acres	%
Cropland	917.2	1,111.5	578.0	426.1	235.8	113.3	0.0	3,381.9	6.0
Pasture 1	269.3	158.7	173.6	226.9	183.0	277.7	0.0	1,289.2	2.3
Pasture 2	55.3	12.7	14.2	15.8	72.6	58.1	0.0	228.7	0.4
Pasture 3	159.5	156.0	65.8	29.0	84.8	40.6	0.0	535.7	0.9
Farmstead	96.1	86.6	59.4	32.1	37.1	141.6	0.0	452.9	0.8
Rural Residential	178.0	98.9	118.3	172.3	51.2	212.0	0.0	830.7	1.5
Urban Residential	12.0	4.5	1.1	0.0	21.0	21.9	0.0	60.5	0.1
Loafing Lot	20.0	75.3	25.0	23.8	0.0	0.0	0.0	144.1	0.3
Forest	324.0	68.0	288.7	71.1	462.4	1,913.8	46,739.8	49,867.8	87.8
Total[a]	2,031.3	1,772.2	1,324.1	997.1	1,147.9	2,779.0	46,739.8	56,791.5	100.0

[a] Component acreages may not sum up to total values due to round-off error
[b] The upper Dry River watershed, represented as a single subwatershed for the purpose of land-use description

Overall, 87.8% of the watershed is forested. However, the upper Dry River watershed, represented as subwatershed DRR-G, accounts for 82.3% of the total watershed acreage and is entirely forested. The lower Dry River watershed, i.e. excluding subwatershed DRR-G, is mainly agricultural with cropland (33.6%) and pastures (20.4%) accounting for 54% of the acreage and forest accounting for 31.4%.

3.5. Potential Fecal Coliform Sources

Potential fecal coliform contributors in the watershed include a wide range of sources, such as humans, pets, livestock, and wildlife. Table 3.3 lists potential fecal coliform sources and daily fecal coliform production rates. Procedures used to calculate populations of different sources are presented in Chapter 4.

The information provided in Table 3.3 is not sufficient to draw conclusions regarding fecal coliform contributions to receiving waters. The potential for a fecal coliform source to contaminate receiving waters depends on factors such as where the waste is generated, how it is stored/handled, and how it is transported to the waterbody. For example, even though the watershed has a sizeable human population, fecal coliform from sewered areas and well-maintained septic systems is unlikely to reach waterbodies in large amounts.

Table 3.3. Potential fecal coliform sources and fecal coliform production by source

Potential source	Population in watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	2,278	1,950[a]
Dairy cattle		
Milk and dry cows	3,485	20,000[b]
Heifers[c]	3,485	9,200[b]
Beef cattle	400	25,800[e]
Pets	802	450[f]
Poultry		
Layers	50,400	136[g]
Broilers	1,153,000	89[g]
Turkeys	369,300	93[g]
Deer	322	347[h]
Raccoon	34	113[h]
Muskrat	49	25[h]
Wood ducks	24 (September - February)[i] 8 (March - May) 0 (June - August)	2,430[g]

[a] Source: Geldreich et al. (1977)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by a milk cow
[e] Based on ASAE (1998) fecal coliform production ratio of beef cattle to milk cow and fecal coliform produced by a milk cow
[f] Source: Weiskel et al. (1996)
[g] Source: ASAE (1998)
[h] Source: Yagow (1999)
[i] Two-thirds of the population is comprised of ducklings with four ducklings for every pair. It is assumed that a duckling produces one-fourth of the fecal coliform compared to an adult.

3.6. Flow and Water Quality Data

Virginia DEQ has been monitoring water quality in the watershed on a monthly basis since September 1993. In conjunction with water quality monitoring, VADEQ conducted stream flow monitoring from September 1993 through September 1996. Stream flow data for the stream flow monitoring period and water quality data for the period of September 1993 through December 1998 were available for this study. Two instantaneous water quality assessments (sweeps) were also conducted by VADEQ while the TMDL project was in progress. Simultaneous flow measurements were also made. The two studies are described in the following sections.

3.6.1. Historic Data

Virginia DEQ personnel monitored stream flow and pollutant concentrations at the Dry River watershed outlet (Station ID No. 1BDUR000.02) (Figure 3.2) on a monthly basis over three years (1993-1996) as part of a study of six watersheds in Rockingham County (VADEQ, 1997). Monthly data can be found in Table 3.4 and Figure 3.3. Figure 3.2 also shows the stream network, including Muddy Creek (Muddy Creek TMDL Establishment Workgroup, 1999). The study objectives were to assess stream conditions, create a database of pollutant concentrations over time, and provide baseline data and contaminant-flow relationships to assist in the development of TMDLs.

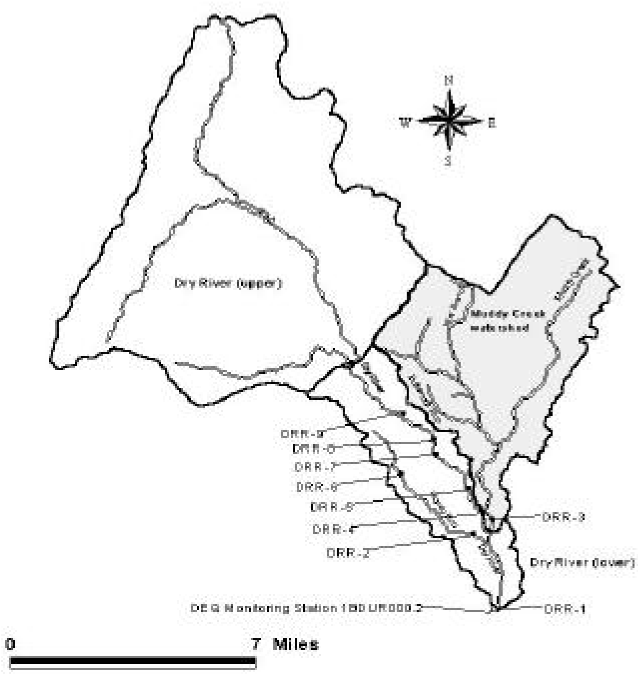

Figure 3.2. Locations of VADEQ and sweep sites for flow measurements and water quality sampling on the lower Dry River. The stream network, including Muddy Creek, is also indicated.

Table 3.4. Monthly data for stream flow measured in Dry River for the period of September 1993 through August 1996 at the monitoring station 1BDUR000.02

Month	Stream flow, cfs		
	Maximum[a]	Mean[a]	Minimum[a]
Jan.	1170.0	532.7	200.0
Feb.	229.0	162.5	77.5
Mar.	323.0	181.0	82.0
Apr.	167.0	94.7	31.5
May	318.0	201.0	113.0
Jun.	252.0	111.0	16.0
Jul.	77.1	45.3	28.2
Aug.	722.0	293.0	43.1
Sep.	18.0	13.2	7.0
Oct.	11.2	10.5	9.7
Nov.	266.0	94.3	8.1
Dec.	72.4	46.9	7.8

[a] Based on three monthly values measured during September 1993 and August 1996

In addition to fecal coliform, the water quality samples were analyzed for nitrate, total nitrogen, and total phosphorus. Time series data of fecal coliform concentration over the September 1993 through December 1998 period are shown in Figure 3.4.

Prior to February 1995, the Most Probable Number (MPN) method was used for analyzing water samples for fecal coliform concentration. The MPN method had a maximum detection limit of 8,000 cfu/100 mL. After February 1995, the more accurate Membrane Filtration Technique (MFT) was used for the analysis of fecal coliform in water samples. The MFT has a maximum detection limit of 16,000 cfu/100 mL. The sample values shown at the maximum detection limit (Figure 3.4) indicate fecal coliform concentrations of at least 16,000 cfu/100 mL. Violations of the water quality standard were observed throughout the reporting period. However, beginning the summer of 1996, it was observed that water quality samples that violated the standard had higher fecal coliform concentrations than in the earlier period.

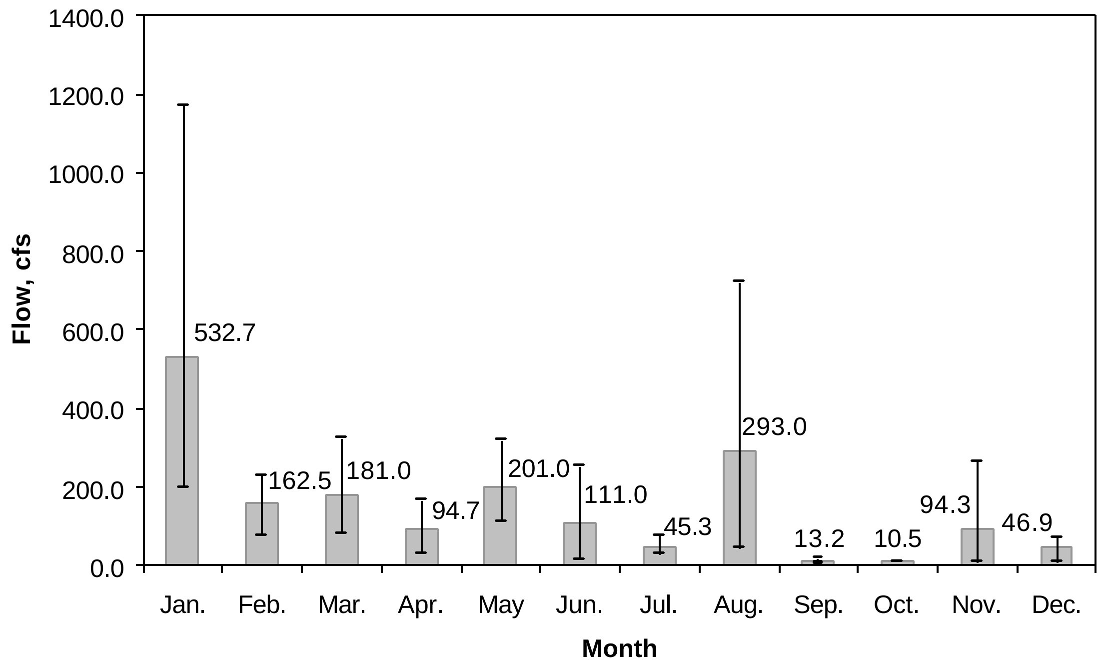

Figure 3.3. Mean monthly stream flow in Dry River for the period September 1993 through August 1996 (monitoring station 1BDUR000.02). Maximum and minimum stream flow values are also indicated.

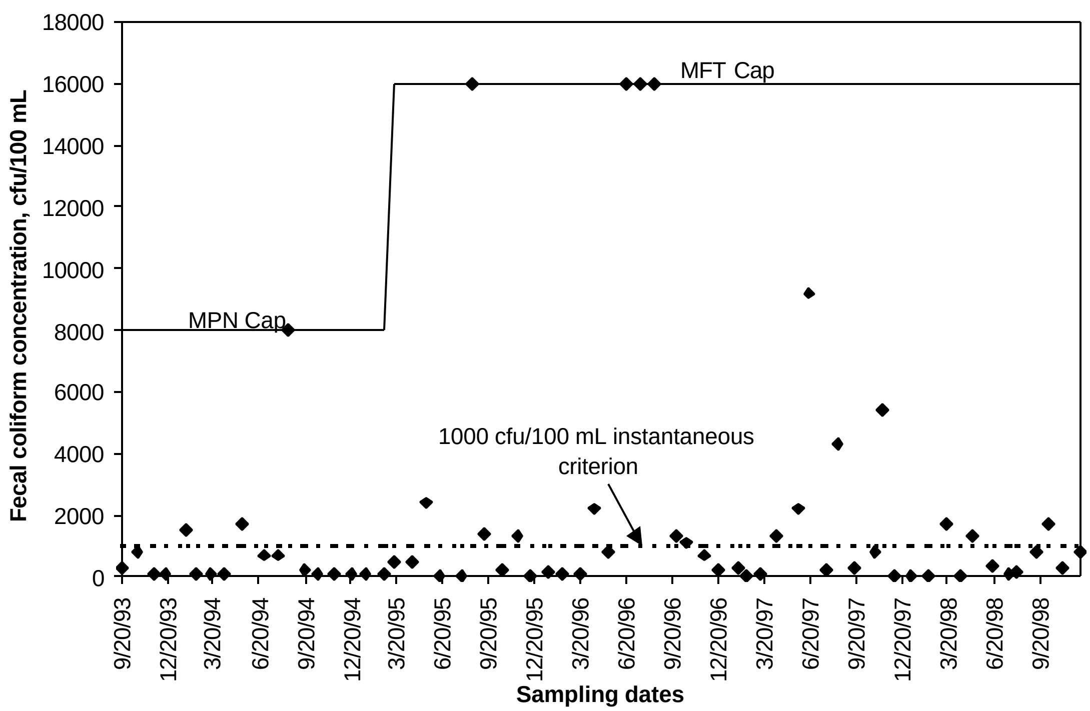

Figure 3.4. Time series of fecal coliform concentration in Dry River at monitoring station 1BDUR000.02.

Thirty two percent of the 64 water samples collected by VADEQ during September 1993 through December 1998 contained fecal coliform concentrations in excess of the instantaneous standard of 1,000 cfu/100 mL (Figure 3.4). Nine percent of the samples contained the highest concentration (16,000 cfu/100 mL) of fecal coliform that could be measured by the MFT method. Given that water samples were collected on a monthly basis, the geometric mean criterion could not be calculated.

The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.4. The stream flow rate and fecal coliform concentration data in Figure 3.5 are for the period from September 1993 through September 1996 period, the period for which both datasets were available.

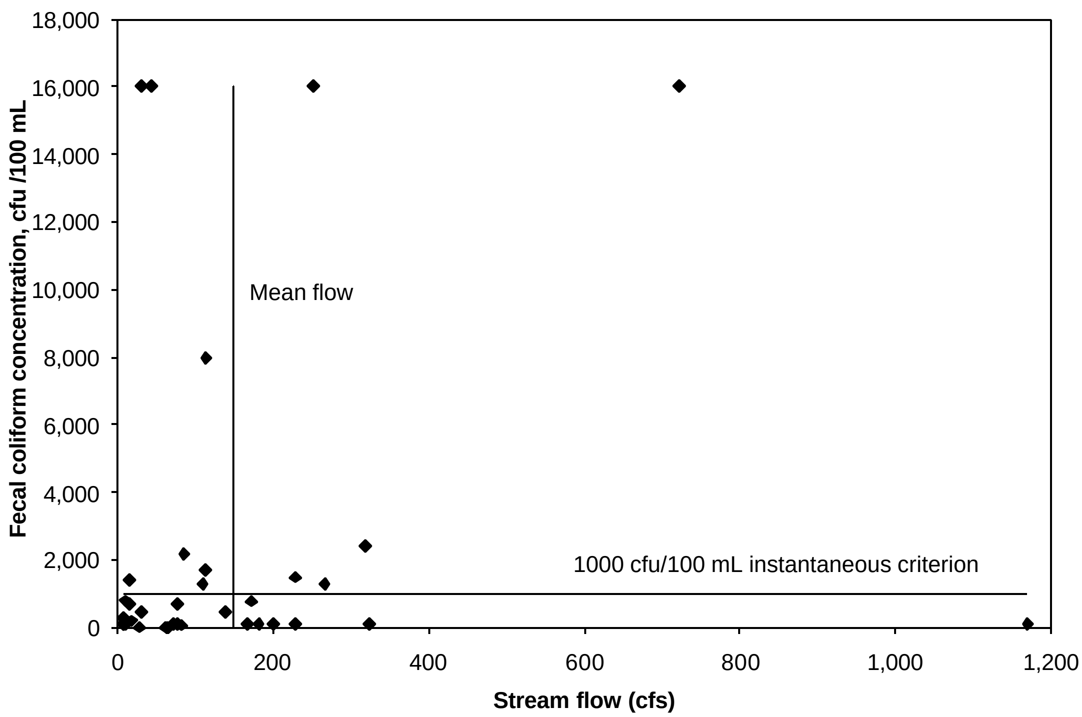

Figure 3.5. Relationship between stream flow and fecal coliform concentration from September 1993 through September 1996.

Based on 37 flow measurements made from September 1993 through September 1996, mean stream flow in Dry River was 147.76 cfs. Twenty eight percent of all fecal coliform samples exceeded the instantaneous standard of 1,000 cfu/100 mL (Figure 3.5) under flows that were lower than the mean value of 147.76 cfs. Under flows higher than the mean value, 41.7% of the samples exceeded the instantaneous standard.   Violations of the instantaneous standard under high-flow conditions indicate that fecal coliform from upland areas could be a significant source of fecal coliform loading to the stream. Also, precipitation events likely cause the ephemeral Honey Run to flow, resulting in increased fecal coliform loading to the Dry River. Violations of the instantaneous standard under low-flow conditions (below mean value) indicate fecal coliform contributions from direct sources, i.e. those not dependent on runoff events.

Seasonality of fecal coliform concentration in the streams was evaluated in terms of mean monthly values (Figure 3.6). Mean monthly fecal coliform concentration was determined as the average of five monthly values over the 1994 through 1998 period.

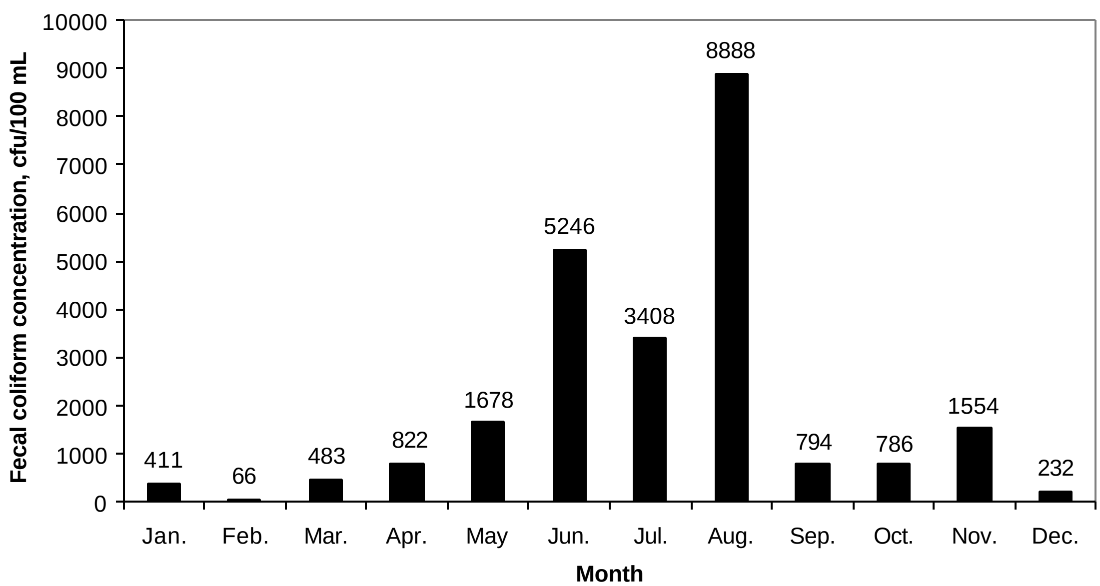

Figure 3.6. Impact of seasonality on fecal coliform concentrations. Average monthly fecal coliform concentration is the mean of five values over a five-year period (1994-1998).

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer months and lower concentrations typically occurring during the winter months. During summer (June – August), the average fecal coliform concentration was 5,847 cfu/100mL compared with 236 cfu/100 mL during winter (December – February). Lower fecal coliform concentrations during the winter and spring months (Figure 3.6), compared with the rest of the year, could be due to larger number of animals being in confinement, resulting in lesser fecal coliform loading to the pasture, and particularly to streams. Further, land application of animal waste is limited during the winter months. Higher fecal concentrations during the summer and fall months could be due to more cattle in streams and more animal waste being land-applied during fall. Fecal coliform concentration was highest during August, the month that has the highest precipitation of all months (SERCC, 2000). Greater precipitation amounts, combined with high intensity events occurring during the summer season, likely result in greater fecal coliform loading not only from the uplands but also from Honey Run (which is otherwise dry) during August. Compared with September and October, higher fecal coliform concentrations observed in November could be due to land application of animal waste during the fall to the winter cover crop and/or to create storage space for animal waste generated during the winter months. Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000 or 16,000), where fecal coliform levels are equal to these maximum levels, the actual counts could be much higher, increasing the averages shown in Figure 3.6.

3.6.2. Water quality sweep and flow measurement

The VADEQ and Virginia Tech conducted two water quality and flow monitoring sweeps on December 1, 1999 and January 18, 2000. The purpose of the sweeps was to assess water quality conditions at various stations within the lower Dry River watershed; no sampling was performed in the upper Dry River watershed. The following factors were considered in selecting the monitoring sites for conducting the sweep.

- the monitoring site should be in close proximity of a road or bridge so that the site would be located on public land with easy access; and
- the monitoring site should be located at the outlet of the subwatershed.

Seven monitoring sites were selected that met the criteria. The sites are described in Table 3.5 and their locations are indicated in Figure 3.2. Sampling began at site DRR-1, close to the watershed outlet and progressed upstream to preclude sample collection at one site from contaminating the sample at the following site. At each site, staff from VADEQ collected two water samples, one from below the stream surface and another at the bottom of the stream (after disturbing the streambed). Samples were stored on ice and were analyzed for fecal coliform using the MPN method within 24 hours by the

Virginia Department of General Services, Division of Consolidated Laboratory Services in Richmond. The MPN method used a maximum detection limit of 16,000 cfu/100 mL. Flow rate was calculated by multiplying the flow velocity (measured with a current meter) with the measured channel cross-sectional area. The results of the sweeps are presented in Table 3.6.

Table 3.5. Location and description of sampling sites for instantaneous water quality and flow assessment

ID	Stream	Location
DRR-1[a]	Dry River	At watershed outlet on North River Road west of Bridgewater
DRR-2	Honey Run	Bridge on Rt. 738 near intersection of Rts. 738 and 743
DRR-3	Dry River	Bridge on Rt. 752 near intersection of Rts. 752 and 737
DRR-4	Muddy Creek	Bridge on Rt. 737 near Rushville
DRR-5	Dry River	Bridge on Rt. 734 near the intersection with Rt. 752
DRR-6	Honey Run	Bridge on Rt. 731 near Clover Hill
DRR-7	Dry River	Bridge on Rt. 613 west of Clover Hill
DRR-8	Dry River	Off of Rt. 732, 0.7 miles south of the intersection of Rts. 732 and 840 near the toe of Cooper Ridge
DRR-9	Dry River	Bridge on Rt. 847 north of Rawley Springs

[a] VADEQ sampling station for stream flow and water quality monitoring (1BDUR000.02)

Sweep 1 (December 1, 1999)

In the 7 days preceding the sweep, a total of 0.41 inches of precipitation was recorded at Dale Enterprise while no precipitation was recorded in the preceding 48 hours. Water samples were not collected at one site (DRR-2) on Honey Run since there was no water (Table 3.6). Of the eight sites where samples were collected, fecal coliform concentrations in the water column (stream surface and bottom) exceeded the instantaneous standard at three sites. Given that the MPN method had an upper detection limit of 16,000 cfu/100 mL, actual fecal coliform concentration could have been much higher since fecal coliform concentrations at two sites were at the 16,000-cap level.

In the upper reaches of the lower Dry River watershed where agricultural activity is less than in the rest of the watershed, fecal coliform concentrations were comparatively low in the water column as evidenced by low counts in DRR-7, DRR-8, and DRR-9 (Table 3.6). Low fecal coliform concentrations in DRR-7 though DRR-9 could also be due the rocky streambed that discouraged cattle from entering the stream. Higher fecal coliform concentrations in the water column were observed in Muddy Creek (DRR-4) and Honey Run (DRR-6). These streams are not only located in intensively farmed areas but also have earthen bottoms that allow cattle to enter the streams. Since there was no flow in the downstream segment of Honey Run (DRR-2), it was likely that Muddy Creek contributed substantially to the fecal coliform concentration observed in the stream surface sample collected at DRR-1.

Table 3.6. Results of the instantaneous fecal coliform and flow assessment

ID	Stream	November 30, 1999			January 18, 2000		
		Flow (cfs)	Fecal coliform counts (cfu/100 mL)		Flow (cfs)	Fecal coliform counts (cfu/100 mL)	
			Stream surface[a]	Stream bottom[b]		Stream surface	Stream bottom
DRR-1[c]	Dry River	-[d]	3,500	130	16.75	330	310
DRR-2	Honey Run	0.00	n/a[e]	n/a	0.00	n/a	n/a
DRR-3	Dry River	119.08	45	330	4.81	170	130
DRR-4	Muddy Creek	12.07	9,200	16,000[f]	0.62	20	18
DRR-5	Dry River	-	40	78	-	18	20
DRR-6	Honey Run	0.09	9,200	16,000	0.003	220	460
DRR-7	Dry River	116.52	20	18[g]	-	n/a	n/a
DRR-8	Dry River	140.97	20	18	2.81	20	18
DRR-9	Dry River	131.83	20	18	51.18	20	20

[a] Sample was obtained from just below the stream surface
[b] Stream bottom was stirred prior to sample collection
[c] VADEQ sampling station (1BDUR000.02)
[d] Flow was not measured
[e] No sample was collected due to the absence of flow
[f] Upper limit of detection
[g] Lower limit of detection

Sweep 2 (January 18, 2000)

In the 7 days preceding the sweep, a total of 0.30 inches of precipitation was recorded at Dale Enterprise while no precipitation was recorded in the preceding 48 hours. Fecal coliform concentration in the water column remained below the instantaneous standard at all seven locations where samples were collected. No samples were collected in two locations. As in the first sweep, samples collected in Dry River at DRR-8 and DRR-9, above the confluence of Dry River and Muddy Creek, had very low fecal coliform concentrations.

Compared to the first sweep, fecal coliform concentrations were generally lower in both the stream surface and bottom water samples in the second sweep. Lower fecal coliform counts in the second sweep (January 2000) compared to the first sweep (November 1999) were supported by the historic data (Figure 3.6). As compared to the first sweep, lower fecal coliform counts in the second sweep, as observed in DRR-1 and DRR-4, could be due to fewer animals in the stream during the winter months resulting in lesser direct deposition of fecal coliform in the stream. In the first sweep, fecal coliform concentrations in the stream surface showed an increasing trend from the headwaters to the outlet; such a trend was not evident in the second sweep.

4. SOURCE ASSESSMENT OF FECAL COLIFORM

Potential fecal coliform sources in the six subwatersheds in the lower Dry River watershed were assessed using multiple approaches, including information from VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Since wildlife is the only source of fecal coliform in the upper Dry River watershed, time series of fecal coliform loading from the upper Dry River watershed to the lower Dry River watershed was calculated using a background concentration of 30 cfu/100mL presented for pristine areas in the Muddy Creek TMDL (Muddy Creek TMDL Establishment Workgroup, 1999) and supported by the water quality sweep data at stations DRR-7, DRR-8 and DRR-9 (Table 3.5). Fecal coliform contributions from Muddy Creek were input as time series based on the previous TMDL assessment for Muddy Creek. There are no permitted point sources of fecal coliform in the lower Dry River watershed. Potential nonpoint sources of fecal coliform in the lower Dry River watershed are described in detail in the following sections.

4.1. Humans and Pets

The lower Dry River watershed has a population of 2,278 people (1999 estimate). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.1.1. Failing Septic Systems

Septic system failure is manifested by the rise of effluent to the soil surface. Surface runoff can then transport the effluent containing fecal coliform to receiving waters. A review of county maps showed no sewered service areas in the watershed. Locations of households with septic systems were then identified using 1999 E-911 digital data (see Glossary) (Rockingham Co. Planning Dept., 1999). Each unsewered household was classified into one of three age categories (pre-1964, 1964-1984, and post-1984) based on USGS 7.5-min. topographic maps which were initially created using 1964 photographs and were photo-revised in 1984. Professional judgment (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.) was applied in assuming that septic system failure rates for houses in the pre-1964, 1964-1984, and post-1984 age categories were 40, 20, and 5%, respectively. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed just north of the study area and Linville Creek), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (Bankson, 2000).

Daily total fecal coliform load to the land from a failing septic system was determined by multiplying the average occupancy rate (2.84 persons, 1990 Census) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1977). Hence, the total fecal coliform loading to the land from a failing septic system was 5.54×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.1.

Table 4.1. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population by subwatershed

Subwatershed	Unsewered houses in each age category (no.)			Failing septic systems (no.)	Pet population[a]
	Pre-1964	1964-1984	Post-1984		
DRR-A	75	51	31	42	157
DRR-B	60	25	58	32	143
DRR-C	55	21	35	28	111
DRR-D	60	33	29	32	122
DRR-E	13	10	28	9	51
DRR-F	95	29	94	49	218
Total	358	169	275	192	802

[a] Assumed an average of one pet per household

4.1.2. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1964 and 1964-1984 age categories, 10% and 2% respectively, were assumed to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, there were no straight pipes in the watershed.

4.1.3. Pets

Assuming one pet per household, there are 802 pets in Dry River watershed. A pet produces 0.45×10^9 cfu/day (Weiskel et al., 1996). Since there are no households in the urban residential land-use category, i.e. no households connected to sewer lines, pet waste in the lower Dry River watershed is generated in the rural residential land-use type only. Fecal coliform loading to streams from pet waste can result from surface runoff transporting fecal coliform from residential areas.

4.2. Cattle

Fecal coliform from cattle can be directly excreted to the stream or it can be transported to the stream from animal waste deposited on pastures or applied to the land.

4.2.1. Distribution of Dairy and Beef Cattle in the lower Dry River Watershed

There are forty-one dairy farms in the watershed. Based on discussion with local producers, the total number of milk and dry cows was estimated at 3,485. The replacement herd of heifers and calves was estimated to be 100% of the dairy herd resulting in a total of 6,970 dairy cattle for the watershed (Table 3.3). Hence, the average dairy herd size was estimated to be 170 cattle. The total dairy cattle population was assigned to the appropriate subwatershed based on the location of the dairies (Table 4.2). The number of dairy operations and loafing lots attached to dairy operations for each subwatershed are also given in Table 4.2. Based on discussion with Virginia Cooperative Extension (VCE) personnel, of the dairy cattle population in the watershed, 42% of the cattle are milk cows, 8% are dry cows, and 50% are heifers.

Table 4.2. Distribution of dairy cattle, dairy operations, loafing lots, and beef cattle between subwatersheds

Subwatershed	Dairy cattle	No. of dairy operations	No. of dairy operations with attached loafing lots	Beef cattle
DRR-A	1,700	10	1	101
DRR-B	2,720	16	9	72
DRR-C	1,530	9	3	50
DRR-D	680	4	2	38
DRR-E	340	2	0	74
DRR-F	0	0	0	65
Total	6,970	41	15	400

Beef cattle in the watershed included cow/calf and feeder operations. The number of beef cattle (400) was estimated for the watershed based on local knowledge. The following procedure was used to estimate beef population by subwatershed (Table 4.2).

1. Based on local knowledge of the watersheds, it was assumed that pastures 1, 2, and 3 had stocking ratios of 1, 2, and 4, respectively, i.e., pasture 2 was stocked with twice the number of animals per acre than on pasture 1. Similarly, it was assumed that pasture 3 was stocked with four times the number of cattle per acre than pasture 1. Accordingly, relative stocking densities (RSDs) for pastures 1, 2, and 3 were 0.14 (1/7), 0.29 (2/7), and 0.57 (4/7), respectively.
2. Fraction of beef cattle in each pasture category was calculated as follows.

   Fraction of beef cattle in pasture 1 =
   $(P_1 \times RSD_1) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3))$

   [4.1a]Fraction of beef cattle in pasture 2 =
   $(P_2 \times RSD_2) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3))$ [4.1b]

   Fraction of beef cattle in pasture 3 =
   $(P_3 \times RSD_3) / ((P_1 \times RSD_1) + (P_2 \times RSD_2) + (P_3 \times RSD_3))$ [4.1c]

   where P_1, P_2, and P_3 = acreages under pastures 1, 2, and 3, respectively. As mentioned earlier, $RSD_1 = 0.14$, $RSD_2 = 0.29$, and $RSD_3 = 0.57$ are relative stocking densities in pastures 1, 2, and 3, respectively.
3. Number of beef cattle in each pasture category was calculated by multiplying the acreage by the fraction of beef cattle in that category. Stocking density for each pasture category was obtained by dividing the number of beef cattle in that pasture category by the acreage. Beef cattle stocking densities for pastures 1, 2, and 3, were 0.12, 0.23, and 0.47 beef cattle/acre, respectively.
4. For each subwatershed, pasture 1 acreage was multiplied by pasture 1 stocking density to calculate number of beef cattle in pasture 1. Similarly, beef cattle numbers were calculated for pastures 2 and 3. Beef cattle population in the subwatershed was obtained by summing the cattle population for all three pasture categories.

Depending on the time of year and type of cattle (i.e., milk cow versus heifer), cattle spend varying amounts of time in different land-use types (i.e., confinement versus pasture). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (thus their manure) among different landuse types and in the stream.

(a) Cattle are confined according to the schedule given in Table 4.3.

(b) When the milk cows are not confined, they spend 25% of the time in the loafing lot and 75% of the time on pasture. However, if a dairy operation does not have an adjacent loafing lot, it is assumed that the milk cows spend all of their unconfined hours in the pastures. All other dairy and beef cattle are on pastures when not in confinement.

Table 4.3. Time spent by cattle in confinement and in the stream

Month	Time spent in confinement (%)		Time spent in the stream (hours/day)[a]
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	30%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

[a] Time spent in and around the stream by cows that have stream access

(c) Pasture 2 (unimproved pasture/grazed woodlands) stocks twice as many cows per unit area as pasture 1 (improved pasture/hayland). Pasture 3 (overgrazed pasture) stocks four times as many cows per unit area as pasture 1.

(d) Cows do not have access to the Dry River in subwatersheds DRR-C and DRR-F (Figure 3.1) since the stream bank is very rocky. However, in the other subwatersheds, cows on pastures that are contiguous to streams (356 acres for all pasture categories) (Table 4.4), have stream access.

(e) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.3). Cows spend more time in the stream during the three summer months, among other things to protect their hooves from hornflies.

(f) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited in pastures.

A sample calculation for determining the dairy cattle numbers to different land-use types and stream in subwatershed DRR-A is shown in Appendix A. The resulting numbers of cattle in each land-use type as well as in the stream for all subwatersheds are given in Table 4.5 for dairy cattle and in Table 4.6 for beef cattle.

Table 4.4. Pasture acreages contiguous to stream

Subwatershed[a]	Pasture 1		Pasture 2		Pasture 3	
	Acres	%[b]	Acres	%	Acres	%
DRR-A	2.4	0.9	36.0	65.1	25.5	16.0
DRR-B	37.7	23.8	8.0	63.2	103.1	66.1
DRR-D	70.8	31.2	0.0	0.0	20.7	71.2
DRR-E	38.3	21.0	14.6	20.1	0.0	0.0
Total	149.2	11.6	58.6	25.6	148.4	27.7

[a] Cattle do not have access to stream in DRR-C and DRR-F due to rocky stream banks

[b] Percent of pasture area contiguous to stream to the total pasture area of that type in that subwatershed

Table 4.5. Distribution of the dairy cattle [a] population

Months	Confined	Loafing lot	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Total
January	3,813	67	912	220	1,952	6	6,970
February	3,813	67	912	220	1,952	6	6,970
March	1,171	161	1,663	403	3,556	16	6,970
April	878	187	1,740	422	3,720	23	6,970
May	878	187	1,737	422	3,712	34	6,970
June	878	188	1,725	419	3,680	80	6,970
July	878	188	1,725	419	3,680	80	6,970
August	878	188	1,725	419	3,680	80	6,970
September	878	187	1,737	422	3,712	34	6,970
October	878	187	1,740	422	3,720	23	6,970
November	1,171	161	1,663	403	3,556	16	6,970
December	3,813	67	912	220	1,952	6	6,970

[a] Includes milk cows, dry cows, and heifers

[b] Number of dairy cattle defecating in stream

Table 4.6. Distribution of the beef cattle population

Months	Confined	Loafing lot	Pasture			Stream[a]	Total
			1	2	3		
January	160	0	81	30	129	0	400
February	160	0	81	30	129	0	400
March	0	0	135	49	215	1	400
April	0	0	135	49	215	1	400
May	0	0	135	49	214	2	400
June	0	0	134	49	213	4	400
July	0	0	134	49	213	4	400
August	0	0	134	49	213	4	400
September	0	0	135	49	214	2	400
October	0	0	135	49	215	1	400
November	0	0	135	49	215	1	400
December	160	0	81	30	129	0	400

[a] Number of beef cattle defecating in stream

4.2.2. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.5) and beef cattle (Table 4.6) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. In this watershed, cattle do not have access to the streams in subwatersheds DRR-C and DRR-F due to the steep stream banks and rocky stream bottoms. Manure loading to streams was calculated from the number and type of cattle in the stream and the waste produced by each type of cattle for each subwatershed. Manure loading increases during the warmer months when cattle spend more time in water compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 533,470 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 298.0×10^9 cfu. Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that mainly dissolved fecal coliform bacteria are transported with the flow. Sediment-bound fecal coliform bacteria are likely to be resuspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.3. Direct Manure Deposition on Pastures

Fecal loading on pastures is contributed by dairy and beef cattle that graze on pastures but do not deposit in streams (Tables 4.5 and 4.6). Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading in lb/ac-day by the fecal coliform concentration of each manure type in cfu/lb. Since the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also changes with season.

Pasture 1, pasture 2, and pasture 3 have average annual manure loadings of 40,789, 81,578, and 163,156 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings on a daily basis averaged over the year are 22.9×10^{9}, 45.7×10^{9}, and 91.4×10^{9} cfu/ac-day for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) irradiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.2.4. Solid Manure Loading in the Loafing Lot

In dairies with loafing lots, milk cows spend 25% of the time in loafing lots when not confined (Table 4.3); milks cows spend the remaining 75% of time in pastures. If a dairy farm does not have an attached loafing lot, the milk cows spend all their unconfined hours on the pasture. It is assumed that other cattle do not spend time on the loafing lot. Total fecal coliform loading on loafing lots was calculated by multiplying the number of milk cows (Table 4.3) in the loafing lot by the total fecal coliform produced per cow each day. Over the entire watershed, average annual manure loading to loafing lots is 28,169 lb/ac. Daily fecal coliform loading to loafing lots is 13.4×10^{9} cfu/ac. Fecal coliform bacteria accumulated on loafing lots are subject to die-off due to desiccation and UV irradiation. Runoff may transport some portion of the remaining fecal coliform to receiving waters.

4.2.5. Direct Loading to Stream from Milking Parlor

Wash-water produced after cleaning cows prior to milking or after washing the milking parlor contains fecal coliform. Since milk cows spend about 2.5% of the total time (0.6 hours/day) in the milking parlor, it was assumed that 2.5% of the fecal coliform produced by milk cows is lost in wash-water. The wash-water may either be stored or released directly into the stream. In a subwatershed, it was assumed that 50% of dairies within 150 ft of streams directly discharged their wash-water into the stream. Based on the above assumption, there was one dairy operation (in DRR-B) releasing 2.87×10^{9} cfu/day directly into the stream. It was assumed that wash-water not released into the stream was applied to loafing lots.

4.2.6. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure/day confined (ASAE, 1998); hence, annual liquid dairy manure production in the watershed is about 7.8 million gallons. Based on the per capita fecal coliform production of milk cows, fresh liquid dairy manure contains 1.18×10^{9} cfu/gal. It was assumed that all liquid dairy manure produced in a subwatershed was applied within the subwatershed. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture 1 land-use categories (VADCR, 1999), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 767.7 acres (22.7%) and 585.2 acres (45.4%) of cropland and pasture 1, respectively. Since there was insufficient liquid dairy manure for cropland and pasture 1, liquid dairy manure was not applied to pasture 2 or pasture 3.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (VADCR, 1999). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil to corn in conventional tillage. In fall, liquid manure is incorporated into the soil in cropland under rye, and surface-applied to cropland under rotational hay. During June through September, liquid manure is surface-applied to pasture 1. It was assumed that only 10%

of the incorporated fecal coliform were available for removal in surface runoff. The application schedule of liquid manure (VADCR, 1999) is given in Table 4.7. Dry cows and heifers were assumed to produce only solid manure.

Table 4.7. Schedule of cattle and poultry waste application

Month	Liquid manure applied (%)[a]	Solid manure or poultry litter applied (%)[a]
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

[a] As percent of annual production

4.2.7. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.8. As in the case of liquid manure, it was assumed that all solid manure produced within a subwatershed is applied to that subwatershed. Amount of solid manure produced in each subwatershed was estimated based on the populations of dry cows, heifers, and beef cattle in the subwatershed (Table 4.2) and their confinement schedules (Table 4.3). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.8). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 4.8). Dry cows and heifers account for 8 and 50% of the total dairy cattle population in each subwatershed, respectively.

Table 4.8. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure for individual cattle type, and weighted average fecal coliform concentration in fresh solid manure.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)	Weighted average fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	558	1,400[a]	115.0[b]	174[c]	233
Heifer	3,485	640[d]	40.7[a]	226[c]	
Beef	400	1,000[e]	60.0[f]	430[c]	

[a] Source: ASAE (1998)
[b] Source: VADCR (1995)
[c] Based on per capita fecal coliform production per day (Table 3.3) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e] Based on discussion with local producers
[f] Source: MWPS (1993)

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture 1, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. During June through September, all solid manure is applied to pasture 1. The method of application of solid manure to cropland or pasture 1 is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.7. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid manure was applied to 307.7 acres (9.1%) and 63.2 acres (4.9%) of the cropland and pasture 1, respectively. Since there was insufficient solid manure for cropland and pasture 1, solid manure was not applied to pasture 2 or pasture 3.

4.3. Poultry

The poultry population (Table 3.3) was estimated based on discussions with local producers and nutrient management specialists. Poultry population numbers thus obtained were found to compare well with poultry housing capacity. Poultry housing capacity was estimated using 1999 E-911 data (length of houses) (Rockingham Co. Planning Dept., 1999) while house widths and space required per bird were determined through discussions with local producers and processors. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied (Table 4.9.). It is not known which poultry litter (layer or broiler or turkey) is applied to a land-use. Hence, a weighted average fecal coliform concentration was estimated for poultry litter based on relative proportions of litter from all poultry types and their respective fecal coliform contents (Table 4.9).

Table 4.9. Estimated daily litter production, litter fecal coliform content for individual poultry types, and weighted average fecal coliform content

Poultry Type	Typical Weight (lb)[a]	Production cycles (per year)[b]	Occupancy factor[c]	Litter produced per bird		Fecal coliform content ($\times 10^9$ cfu/lb)[f]	Weighted average fecal coliform content ($\times 10^9$ cfu/lb)
				(lb/ cycle)[d]	(lb/ day)[e]		
Layer	4	1.09	0.96	30.0	0.09	1.46	
Broiler	2	6	0.79	2.6	0.04	1.65	0.97
Turkey	15	5	0.87	18.0	0.25	0.33	

[a] Source: ASAE (1998)
[b] Based on information from VADCR and producers
[c] Fraction of time when the poultry house is occupied; layer – 46 weeks/48 weeks; broiler – 48 days/61 days; turkey (5 cycles) – 45 weeks/52 weeks
[d] Source: VADCR (1999)
[e] Litter produced per bird per day is equal to the product of production cycles per year and litter produced per cycle divided by number of days in a year.
[f] Fecal content in litter is equal to fecal coliform produced per day per bird (Table 3.3) multiplied by the occupancy factor, divided by the litter produced per day per bird.

Since poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. Poultry litter is applied at 3 tons/ac-year to cropland and pasture 1, in order of priority. After application to cropland and pasture 1, litter is applied to pastures 2 and 3 at 1.5 tons/ac-year, in order of priority. Method of poultry litter application to cropland and pastures is assumed to be identical to the method of cattle manure application. Application schedule of poultry litter is given in Table 4.7. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 2,306.3 acres (68.2%), 640.6 acres (49.7%), 228.7 acres (100.0%), and 535.6 acres (100.0%) of the cropland, pasture 1, pasture 2, and pasture 3, respectively.

Of the 26,435 tons of poultry litter produced in the watershed, there was enough land to apply only 9,517 tons within the watershed. It was assumed that the remaining poultry litter (64% of the total production) was exported from the watershed. Given that poultry litter is lighter to transport than cattle manure, poultry litter produced within the watershed was assumed to be applied throughout the watershed irrespective of the subwatershed in which it is produced. Poultry litter was allocated to subwatersheds as a fraction of the amount required within the watershed as follows:

$$PL_i = \frac{((CL_i + P1_i) \times AF_1) + ((P2_i + P3_i) \times AF_2)}{\sum_{i=1}^{N} \{((CL_i + P1_i) \times AF_1) + ((P2_i + P3_i) \times AF_2)\}} \qquad [4.2]$$

where,

- N = number of subwatersheds in the watershed (6);
- CL_i = Cropland acreage in subwatershed i;
- $P1_i$ = Pasture 1 acreage in subwatershed i;
- $P2_i$ = Pasture 2 acreage in subwatershed i;
- $P3_i$ = Pasture 3 acreage in subwatershed i;
- AF_1 = Application factor, considered one for cropland and pasture 1; and
- AF_2 = Application factor, considered 1/2 for pastures 2 and 3 that have one-half application rate as compared to cropland and pasture 1.

Using Equation [4.2], poultry litter amounts were assigned to individual subwatersheds as percent of total poultry litter produced within the watershed (Table 4.10).

Table 4.10. Distribution of poultry litter between the subwatersheds

Subwatershed	Poultry litter[a] (%)
DRR-A	25
DRR-B	27
DRR-C	16
DRR-D	13
DRR-E	10
DRR-F	9
Total	100

[a] Percent of total assigned to (but not necessarily produced in) the subwatershed

4.4. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Extensive watershed reconnaissance was undertaken to identify different species of wildlife, determine population numbers, and assess habitat in the watershed to support and supplement information provided by VADGIF. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 3.3) along with preferred habitat and habitat area (Table 4.11).

Table 4.11. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Percent direct fecal deposition in streams
Deer	Forested areas and adjacent pastures with continuous water supply	8,563	1
Raccoon	Forested areas within ½ mile on either side of stream[a]	1,431	10
Muskrat	150 ft on either side of stream	99	25
Wood duck	¼ mile on either side of stream	211	25

[a] Based on Reach 3 files

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams based upon habitat (Table 4.11). Fecal matter produced by deer that is not directly deposited in streams, is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures. Wood ducks deposit their waste in streams and forests.

Fecal loading from wildlife was estimated for each subwatershed. A deer population of 322 animals was estimated using a density of 24 deer/mi.^{2} of watershed area (VADGIF). The deer population was distributed among the subwatersheds based on pasture and forest acreage in the subwatershed as a fraction of pasture plus forest area in the entire watershed. Due to unsuitable habitat, it was assumed that there were no raccoons in subwatersheds DRR-B, DRR-D, and DRR-E. In the other subwatersheds, raccoon populations were estimated using a density of 15 raccoons/mi.^{2} of habitat (VADGIF). A minimal density of 0.5 muskrats/ac of habitat was assumed in view of very little evidence of muskrat activity in subwatershed DRR-A. Given the lack of suitable habitat, it was assumed that the other subwatersheds did not have muskrats. Based on a wood duck density of two wood ducks/50 acres of habitat, subwatershed DRR-A had a wood duck population of eight ducks during March through May (spring). During September through February (fall - winter), the wood duck population triples due to the presence of ducklings. During June through August (summer), there are no wood ducks in the watershed. Due to lack of suitable habitat, there are no wood ducks in the other subwatersheds. Distribution of wildlife among subwatersheds is given in Table 4.12.

Table 4.12. Distribution of wildlife among subwatersheds

Subwatershed	Wildlife numbers			
	Deer	**Raccoon**	**Muskrat**	**Wood ducks[a]**
DRR-A	65	7	49	24/8/0
DRR-B	57	0	0	0/0/0
DRR-C	42	7	0	0/0/0
DRR-D	29	0	0	0/0/0
DRR-E	39	0	0	0/0/0
DRR-F	90	20	0	0/0/0
Total	322	34	49	24/8/0

[a] Population during September – February/population during March – May/population during June – August, respectively

4.5. Summary: Contribution from All Sources

Monthly fecal coliform deposition and percent breakdown in different locations in the watershed is given in Table 4.13. It should be noted that Table 4.13 does not reflect either storage losses of fecal coliform collected in confined animal structures or the distribution of fecal coliform to cropland and pasture from land application of manure.

Table 4.13 presents information on waste produced by confined cattle and poultry which is collected for storage and, does not reflect eventual application of the waste to cropland and pastures. For the periods not in confinement, cattle manure is distributed to pasture with small fractions going to loafing lot or directly into streams. Failing septic systems and pet waste contribute to fecal coliform loads in the rural residential and farmstead categories. Since there are no urban residential areas in the watershed, there is no loading to this land-use category from pets. Wildlife species contribute fecal coliform directly to stream, to pastures and forests.

It is clear from Table 4.13 that more than 97% of the fecal coliform is produced in confinement and on pastures. Since waste produced in confinement is eventually applied to cropland and pastures, it could be prematurely assumed that more than 97% of fecal coliform loading in streams originates from croplands and pastures. However, in addition to fecal coliform production, die-off of fecal coliform and transport of fecal coliform to receiving waters have to be considered in estimating fecal coliform loads in streams. Fecal coliform die-off can occur in storage with die-off rates varying with storage conditions. Fecal coliform die-off on land depends on environmental factors, type of fecal coliform source (e.g., poultry waste versus liquid manure), and application method (e.g., incorporation versus surface broadcast). Finally, soil (e.g., soil texture), environmental (e.g., intensity of precipitation), geographic (e.g., distance to stream), and cultural (e.g., waste application method) factors will also affect how much of the applied fecal coliform reaches the waterbody. All three factors were considered in estimating fecal coliform loads to receiving waters as described in Chapter 5.

Table 4.13. Monthly fecal coliform deposition in different locations in lower Dry River watershed

Month	Confinement		Pasture 1[a]		Pasture 2[a]		Pasture 3[a]		Rural Residential[b]		Farmstead[c]		Urban Residential[d]		Loafing lot		Forest		Stream[e]		Total[f] (´ 10^{12} cfu)
	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	´ 10^{12} cfu	%	
Jan	5,658	78.6	469	6.5	166	2.3	778	10.8	43	0.6	43	0.6	0	0.0	33	0.5	3	0.0	2	0.0	7,194
Feb	5,293	78.6	438	6.5	155	2.3	728	10.8	40	0.6	40	0.6	0	0.0	31	0.5	3	0.0	2	0.0	6,730
Mar	4,361	60.6	882	12.3	313	4.3	1,465	20.4	43	0.6	43	0.6	0	0.0	80	1.1	2	0.0	5	0.1	7,194
Apr	4,045	58.1	907	13.0	322	4.6	1,506	21.6	42	0.6	42	0.6	0	0.0	90	1.3	2	0.0	7	0.1	6,961
May	4,180	58.1	936	13.0	332	4.6	1,555	21.6	43	0.6	43	0.6	0	0.0	93	1.3	2	0.0	10	0.1	7,194
Jun	4,045	58.1	902	13.0	320	4.6	1,498	21.5	42	0.6	42	0.6	0	0.0	90	1.3	2	0.0	22	0.3	6,961
Jul	4,180	58.1	932	13.0	330	4.6	1,548	21.5	43	0.6	43	0.6	0	0.0	93	1.3	2	0.0	23	0.3	7,193
Aug	4,180	58.1	932	13.0	330	4.6	1,548	21.5	43	0.6	43	0.6	0	0.0	93	1.3	2	0.0	23	0.3	7,193
Sep	4,045	58.1	906	13.0	321	4.6	1,504	21.6	42	0.6	42	0.6	0	0.0	90	1.3	3	0.0	10	0.1	6,962
Oct	4,180	58.1	937	13.0	332	4.6	1,556	21.6	43	0.6	43	0.6	0	0.0	93	1.3	3	0.0	7	0.1	7,194
Nov	4,221	60.6	853	12.3	303	4.3	1,418	20.4	42	0.6	42	0.6	0	0.0	77	1.1	3	0.0	5	0.1	6,962
Dec	5,658	78.6	469	6.5	166	2.3	778	10.8	43	0.6	43	0.6	0	0.0	33	0.5	3	0.0	2	0.0	7,194
Total	54,044	63.6	9,561	11.3	3,391	4.0	15,880	18.7	507	0.6	507	0.6	0	0.0	895	1.1	30	0.0	117	0.1	84,931

[a] Contribution from pastured cattle and wildlife
[b] Contribution from failing septic systems and pets in unsewered households
[c] Assumed equal to rural residential
[d] Since there are no sewered households, there is no contribution from pets
[e] Contribution from cattle and wildlife depositing in streams and milking parlor wash-off
[f] Fecal coliform production or percentage from different locations may not sum to total values due to rounding error

5. MODELING PROCESS FOR TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, model description, input data requirements, model calibration procedure and results, and model validation results are discussed.

5.1. Model Description

TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) (Bicknell et al., 1997) was used to model fecal coliform transport and fate in the Dry River watershed. The BASINS interface (Better Assessment Science Integrating Point and Nonpoint Sources System) Version 2.0 (Lahlou et al., 1998) was used to facilitate use of HSPF. Specifically, the NPSM interface within BASINS provides pre- and post-processing support for HSPF. The ArcView 3.0a or 3.1 GIS provides the integrating framework for BASINS and allows the display and analysis of landscape information.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Donigian et al., 1995). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules, HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module.

5.2. Selection of Subwatersheds

The Dry River watershed is a moderately-sized watershed (56,792 ac) and the model framework selected is suitable for this size. Since fecal coliform and flow contributions from Muddy Creek were input as time series based on the result of a previous assessment for Muddy Creek, (Muddy Creek TMDL Establishment Workgroup, 1999), the Muddy Creek subwatershed was not modeled separately. The forested upper Dry River watershed was divided into five subwatersheds. However, the lower Dry River watershed has the different types of land-use scattered throughout the watershed. To account for the spatial variation of fecal coliform sources, the lower Dry River watershed was divided into six subwatersheds. Since loadings of fecal coliform are believed to be associated with the type of land-use activities and the degree of development in the watershed, the six subwatersheds were chosen based on uniformity of land-use. The stream network was delineated based on the blue lines on USGS topographic maps with each subwatershed having at least one stream segment. For the upper Dry River watershed, a background fecal coliform concentration of 30 cfu/100 mL (Muddy Creek TMDL Establishment Workgroup, 1999) was assumed. The time series of flow rate and fecal coliform concentrations from upper Dry River and Muddy Creek were supplied as point source inputs to the model.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land-use characteristics of the watershed. The different types and sources of input data used to develop the TMDL for the Dry River watershed are discussed below.

5.3.1. Climatological Data

Required weather data were obtained from the weather station closest to the watershed. Hourly precipitation data were obtained from the National Climatic Data Center's (NCDC) cooperative weather station at Dale Enterprise, located 4.6 miles from the watershed outlet and within 17 miles of the most distant parts of the watershed. Since hourly data for other meteorological parameters, such as solar radiation and temperature were not available at Dale Enterprise, daily measured or simulated data from Monterey (Virginia), Lynchburg Airport, and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF. Missing hourly precipitation data were filled in by disaggregating daily precipitation data from Dale Enterprise using hourly precipitation data from Staunton Sewage Plant as the template data set. Daily precipitation data from Timberville were used to verify daily precipitation data from Dale Enterprise. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set is described in Appendix B.

5.3.2. Hydrologic Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land-use category for each subwatershed. For each reach in the watershed, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Donigian et al., 1995). Information on stream geometry in each subwatershed is presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in Appendix B.1 of BASINS ver. 2.0 User's Manual (Lahlou et al., 1998). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given Appendix B.1 of BASINS ver. 2.0 User's Manual (Lahlou et al., 1998). Runoff estimated by the model is also an input to the water quality components. Values for the parameters were estimated based on local conditions when possible, otherwise the default parameters provided within HSPF were used.

Table 5.1. Stream characteristics of the lower Dry River watershed

Subwatershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
DRR-A	2.69	18.7	5. 5	0.0053
DRR-B	2.58	17.7	1.6	0.0070
DRR-C	3.76	107.0	3.9	0.0083
DRR-D	1.16	17.7	1.6	0.0098
DRR-E	1.68	17.7	1.6	0.0119
DRR-F	4.13	124.0	2.9	0.0096

5.3.3. Land-use

Virginia DCR identified 31 land-use types in the watershed. As described in Chapter 3, the 31 land-use types were consolidated into nine categories based on hydrologic and waste application/production characteristics (Table 3.1). The land-use categories were assigned pervious/impervious percentages which allowed a land-use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Land-use data were used to select several hydrology and water quality parameters for the simulations.

5.4. Accounting for Pollutant Sources

5.4.1. Overview

There is one VADEQ permitted point source discharge in the Dry River watershed that is located in the Muddy Creek subwatershed. This point source was not considered as an individual point source in the present analysis because the entire discharge from the Muddy Creek watershed was represented in this study as a point source input to the Dry River. Thus, the permitted point source discharge in Muddy Creek subwatershed was represented as part of the overall Muddy Creek discharge. The Muddy Creek discharge was converted to a point source loading using time series output (simulated daily flow and fecal coliform loadings) from the Fecal Coliform TMDL Development for Muddy Creek, Virginia project report (May 1999) for the existing condition, the TMDL allocation, and the Phase 1 Allocation scenarios. Within the lower Dry River watershed (excluding the Muddy Creek and upper Dry River watersheds), fecal coliform loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as a nonpoint source loading and part of that load was available for transport to the stream system as a result of surface runoff. Direct nonpoint source loadings were applied to the stream reach in each subwatershed as appropriate.

The nonpoint source loadings were applied as fecal coliform counts to each land-use category in a subwatershed on a monthly basis. Fecal coliform was considered to die-off in land-applied sources, stored manure, and in the stream. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences.

5.4.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using a first order die-off equation of the form:

$$C_t = C_0 10^{-Kt} \qquad [5\text{-}1]$$

where: C_t = concentration or load at time t, C_0 = starting concentration or load, K = decay rate (day^{-1}), and t = time in days. A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the lower Dry River watershed (Table 5.2).

Table 5.2. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources

Waste type	Storage/application	Decay rate, day^{-1}	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971)[a]
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973)[a]
Poultry litter	Soil surface	0.035	Giddens et al. (1973)
		0.342	Crane et al. (1980)

[a] Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Since the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoon (0.375) was used assuming that the storage creates anaerobic conditions.
- Solid cattle manure: Based on the range of decay rates (0.028-0.066) reported for solid dairy manure, a decay rate of 0.05 was used assuming that a majority of manure piles are not covered.

- Poultry waste in pile/house: Since no decay rates were found for poultry waste in storage, a decay rate of 0.035 was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 (Table 5.2.) since fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and lack of predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in Appendix C. The method used to calculate the fraction of fecal coliform surviving in the manure at the end of storage considered the duration of storage, type of storage, type of manure, and die-off factor. When calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land was estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 1.15 day^{-1} (USEPA, 1985) was used.

5.4.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required runoff for transport to streams. Fecal coliform loading available for surface transport by land-use for all sources in the watershed is presented in Table 5.3**.** Total manure production was calculated using animal population and waste produced per day per animal. Animal numbers for the watershed were supplied by VADCR. These numbers were further refined by consulting with producers and Virginia Cooperative Extension faculty located in that county. The refined animal numbers were also checked against pasture acreage (for beef) and housing capacity (for poultry) to ensure that the estimates were reasonable. For dairy cattle population, the number of dairies in each subwatershed and the number of dairy cattle in each dairy farm were estimated in consultation with producers. The numbers on daily waste production from different animal species were obtained from published sources such as the ASAE Standards or Virginia Nutrient Management Standards Criteria. Estimation of manure produced in different locations (e.g., confinement, pastures) were based on guidelines provided by VADCR which were confirmed or modified through discussion with producers and extension personnel. Fecal coliform content in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture 1. Fecal coliform loadings to each subwatershed are presented in Appendix D.

Table 5.3. Monthly nonpoint fecal coliform loadings to the different land-use categories excludes Muddy Creek and upper Dry River subwatersheds

Month	Fecal coliform loadings (´ 10^{12} cfu/month)									Total by month
	Crop -land	Past. 1	Past. 2	Past. 3	Rural Resid- ential	Farm- stead	Urban Resid- ential	Loafing lot	Forest	
Jan.	0	424	111	869	43	43	0	41	2	1,533
Feb.	229	396	107	821	40	40	0	39	2	1,674
Mar.	1,146	794	223	1,675	43	43	0	100	2	4,026
Apr.	917	815	224	1,714	41	41	0	112	2	3,867
May	229	841	221	1,743	43	43	0	116	2	3,238
Jun.	0	1,108	221	1,710	41	41	0	112	2	3,236
Jul.	0	1,104	228	1,766	43	43	0	116	2	3,300
Aug.	0	1,119	228	1,766	43	43	0	116	2	3,316
Sep.	0	1,398	233	1,769	41	41	0	112	2	3,597
Oct.	339	842	225	1,754	43	43	0	116	2	3,364
Nov.	349	769	206	1,599	41	41	0	96	2	3,105
Dec.	0	424	111	869	43	43	0	41	2	1,533
Total	3,210	10,034	2,335	18,054	506	506	0	1,119	26	35,790

Of all the fecal coliform excreted in the watershed (excluding fecal coliform deposited in the stream) (Table 4.13), 57.9% of the coliform die-off in storage prior to land application and the remaining 42.1% is applied to the land as a NPS load (Table 5.3). The sources of fecal coliform to different land-use categories in the lower Dry River watershed and how they were represented in the model are briefly discussed below.

1. Cropland: Liquid dairy manure, solid manure, and poultry litter is applied to cropland as described in Chapter 4. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application (Sections 4.2.1, 4.2.2, and 4.3). For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a subwatershed. The loading rate varied by month and subwatershed.

2. Pasture 1: In addition to direct deposition from cattle and wildlife, pasture 1 receives applications of liquid dairy manure, solid manure, and poultry litter as described in Chapter 4. Fecal coliform loadings from stored manure and litter to pasture 1 were reduced to account for die-off during storage. For modeling, monthly fecal coliform loading assigned to pasture 1 was distributed over the entire pasture 1 acreage within a subwatershed.
3. Pasture 2 and pasture 3: Fecal coliform loadings resulting from direct waste deposition by cattle and wildlife were spread over pasture 2 and pasture 3 acreages, in each subwatershed.
4. Rural Residential: Fecal coliform loading on rural residential land use came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a subwatershed (Table 4.1) were combined and assumed to be uniformly applied to the rural residential land-use areas.
5. Farmstead: The total fecal coliform load to farmstead was assumed to be the same as loads for the rural residential land-use, for lack of better information specific to farmsteads.
6. Urban Residential: Since there are no sewered households in the watershed, there are no pets in the urban residential areas. Hence, there is no load to the urban residential land-use in the watershed.
7. Loafing Lot: Fecal coliform loads resulting from direct waste deposition by milk cows in loafing lots were spread uniformly over the entire loafing lot acreage in each subwatershed.
8. Forest: Wildlife not defecating in streams and pastures provided fecal coliform loading to the forest. The fecal coliform load, except for the percentage considered as a direct load to the stream, was applied uniformly over the forest areas.

5.4.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources were the result of direct deposition of excreta into streams by cattle and wildlife and a straight pipe from one milking parlor that was assumed to discharge directly to a stream (Table 5.4). It was assumed that there were no direct nonpoint sources in the upper Dry River watershed because it was almost entirely forested and the wildlife load was represented by a constant background concentration of 30 cfu/100mL discussed earlier. Direct nonpoint source loading to the stream is 0.5% of the total fecal coliform load applied to the land in the lower Dry River watershed (Tables 5.3 and 5.4).

Table 5.4. Monthly direct nonpoint source loads to the stream by subwatershed

Month	Monthly fecal coliform loads by subwatershed (´ 10^9 cfu/month)[a]													Monthly loading (´ 10^9 cfu)
	DRR-A		DRR-B			DRR-C		DRR-D		DRR-E		DRR-F		
	Cattle	Wild life	Cattle	Wild life	Milk parlor	Cattle	Wild life	Cattle	Wil dlif e	Cattle	Wild life	Cat tle	Wild life	
Jan.	381	244	1,798	6	39	0	6	346	3	85	4	0	13	2,925
Feb.	356	228	1,682	6	36	0	5	323	3	80	4	0	12	2,735
Mar.	1,081	168	5,099	6	93	0	6	973	3	228	4	0	13	7,674
Apr.	1,486	163	7,004	6	105	0	5	1,333	3	306	4	0	12	10,427
May	2,303	168	10,857	6	109	0	6	2,065	3	474	4	0	13	16,008
Jun.	5,199	17	24,515	6	105	0	5	4,664	3	1,069	4	0	12	35,599
Jul.	5,373	18	25,332	6	109	0	6	4,819	3	1,105	4	0	13	36,788
Aug.	5,373	18	25,332	6	109	0	6	4,819	3	1,105	4	0	13	36,788
Sep.	2,228	236	10,507	6	105	0	5	1,999	3	458	4	0	12	15,563
Oct.	1,535	244	7,238	6	109	0	6	1,377	3	316	4	0	13	10,851
Nov.	1,046	236	4,935	6	90	0	5	942	3	221	4	0	12	7,500
Dec.	381	244	1,798	6	39	0	6	346	3	85	4	0	13	2,925
Total	26,742	1,984	126,097	72	1,048	0	67	24,006	36	5,532	48	0	151	185,783

[a] Fecal coliform loads applied by cattle, wildlife, and milk parlor wash-off directly to streams

5.5. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component, and the calibration results of the water quality component are presented.

5.5.1. Hydrology

<u>Procedure</u>

For the hydrologic component of the HSPF calibration, observed values for daily stream flow are required. Although monthly observations of stream flow are available for Dry River for a 37-month period, daily discharge records are not available. Daily discharge observations are available from two USGS flow-monitoring stations located in watersheds near Dry River. The USGS station at Mount Clinton, Virginia (Station Number 01621050) has daily discharge observations for a portion of the Muddy Creek watershed. The drainage area monitored at the station is 14.2 square miles (9,088 acres) and the available period of record is April 1993 through September 1998 (approximately 5 years). The other USGS station is located near Broadway, Virginia (Station Number 01632982), and has daily discharge observations for the Linville Creek watershed. The drainage area monitored at the station is 45.5 square miles (29,120 acres) and the available period of record is August 1985 through September 1998 (approximately 13 years).

The locations of the Linville Creek and Muddy Creek watersheds relative to Dry River watershed are shown in Figure 5.1. Dry River is located in the same hydrologic unit as Muddy Creek (South Fork Shenandoah River basin), whereas Linville Creek is located in the North Fork Shenandoah River basin. The National Climatic Data Center's (NCDC) hourly precipitation gage at Dale Enterprise (Figure 5.1) was the main gage used for model calibration and the NCDC daily precipitation data at Timberville were used to verify and supplement the Dale Enterprise data.

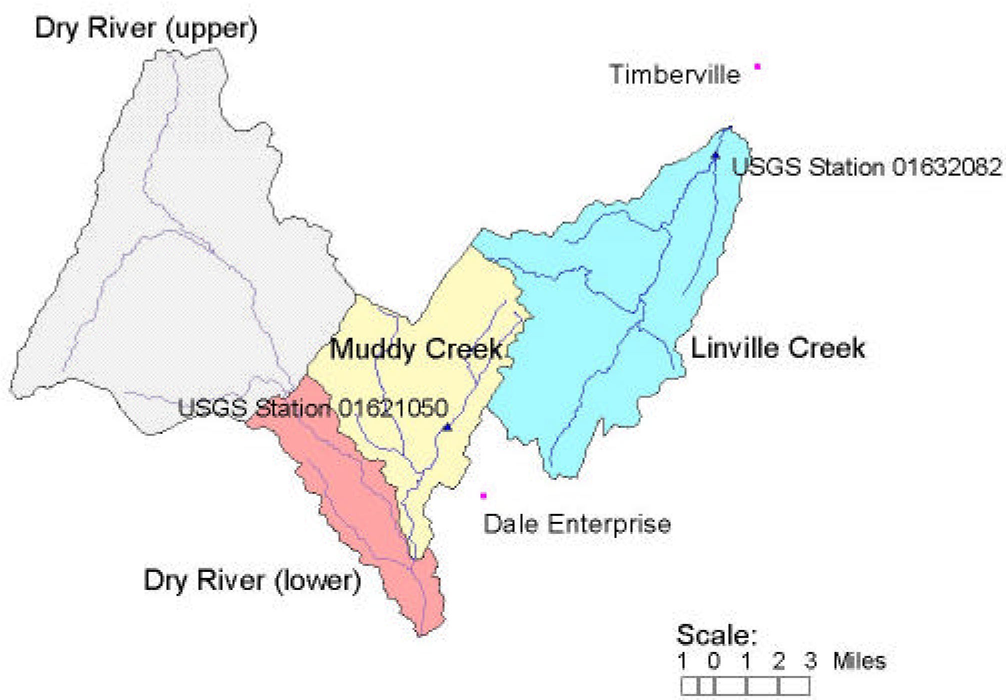

Figure 5.1. Location of calibration and validation watersheds relative to the Dry River watershed.

The hydrology calibration was performed using the Linville Creek data because the period of record was longer than that available for the Muddy Creek watershed. Because of their close geographic locations and similarities in land-use activities with the lower Dry River watershed, data from the Linville Creek and Muddy Creek watersheds were considered to be appropriate for use in the calibration. This longer period of record ensured that a representative time period that included both wet and dry periods was included in the calibration period. Furthermore, the longer period of record from Linville Creek provided enough data to conduct validation runs of the same length as the calibration runs. The calibration period selected for the Linville Creek data was September 1, 1991 to March 1, 1996, and the validation period was September 1, 1986 to August 31, 1991. The Muddy Creek daily discharge observations were also used as an independent evaluation of the calibrated input data set. The period of record used from Muddy Creek was April 13, 1993 to July 31, 1996. The additional validation runs using the Muddy Creek data provided a measure of the transferability of the calibrated data set from Linville Creek to other nearby watersheds.

The HSPEXP decision support software (Lumb et al. 1994) was used to develop a calibrated HSPF data set for Linville Creek. The HSPEXP system provides guidance on parameter adjustment during the calibration process. This guidance is provided through a decision support system that is based on the experience of expert modelers in applying HSPF to various types of watersheds (Lumb et al. 1994). Accuracy of HSPF simulation results is measured in HSPEXP by comparing simulated and observed daily discharge values. Comparison of simulated and observed data is conducted for several parameters including annual water balances, seasonal variability of baseflow, and storm events, and for the overall time series. HSPEXP requires the user to identify a set of storms to investigate the accuracy of the simulated storm response during each season. Guidance for storm selection is given in the HSPEXP user manual (Lumb et al. 1994). For the calibration period, 29 storm events were selected from the Linville Creek watershed. For the validation period, 24 storm events were selected from Linville Creek and seven from Muddy Creek. Fewer storms were used for Muddy Creek because of the shorter available period of record. Values for parameters that represent the different levels of accuracy are calculated for both the simulated and observed data and compared as a percent error in HSPEXP. The guidance provided by HSPEXP is based on the percent error between the various observed and simulated values for each parameter (Lumb et al. 1994). The default criteria recommended in HSPEXP were used in the Linville Creek calibration and are listed in Table 5.5. These same criteria were used in the validation of the model.

Table 5.5. Calibration Criteria Used in HSPEXP for Hydrologic Calibration.

Variable	Percent Error Criteria
Total Volume	10%
Low Flow Recession	0.010%
50% Lowest Flows	10%
10 % Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

Results

The calibration of the HSPF hydrology parameters resulted in simulated flows that accurately matched the observed data for Linville Creek. A comparison of the simulated and observed stream flow data is given in Table 5.6 for the calibration period of September 1, 1991 to March 1, 1996 for Linville Creek. There was very good agreement between the observed and simulated stream flow indicating that the model represented the hydrologic characteristics of the watershed very well. Percent error for each variable is within the criteria specified by HSPEXP. In Figure 5.2, the simulated and observed stream flow for a shorter period within the calibration period is shown. The simulated data follow the pattern of the observed data very well. The model closely simulates both base flow conditions and storm peaks.

Table 5.6. Linville Creek calibration simulation results (September 1, 1991 to March 1, 1996).

Parameter	Simulated (inches)	Observed (inches)	% Percent Error
Total stream flow	54.9	55.2	-0.5%
Summer[a] stream flow	7.6	7.5	0.01%
Winter[b] stream flow	20.2	21.5	-6.0%

[a] June – August
[b] December - February

The calibrated data set was then used in the model to predict runoff for a different time period for Linville Creek to provide a basis for evaluating the appropriateness of the calibrated parameters. A comparison of the simulated and observed stream flow data is given in Table 5.7 for the validation period of September 1, 1986 to August 31, 1991 for Linville Creek.

Table 5.7. Linville Creek validation simulation results (September 1, 1986 to August 31, 1991).

Parameter	Simulated (inches)	Observed (inches)	% Percent Error
Total stream flow	51.4	48.0	7.1%
Summer[a] stream flow	7.5	6.5	15.4%
Winter[b] stream flow	15.6	14.4	8.3%

[a] June – August
[b] December - February

There was very good agreement between the observed and simulated stream flow, indicating that the calibrated parameters represent the characteristics of the watershed reasonably well for time periods in addition to the calibration period. The simulated and observed stream flow for a shorter period within the validation period is shown (Figure 5.3). The simulated data follow the pattern of the observed data well.

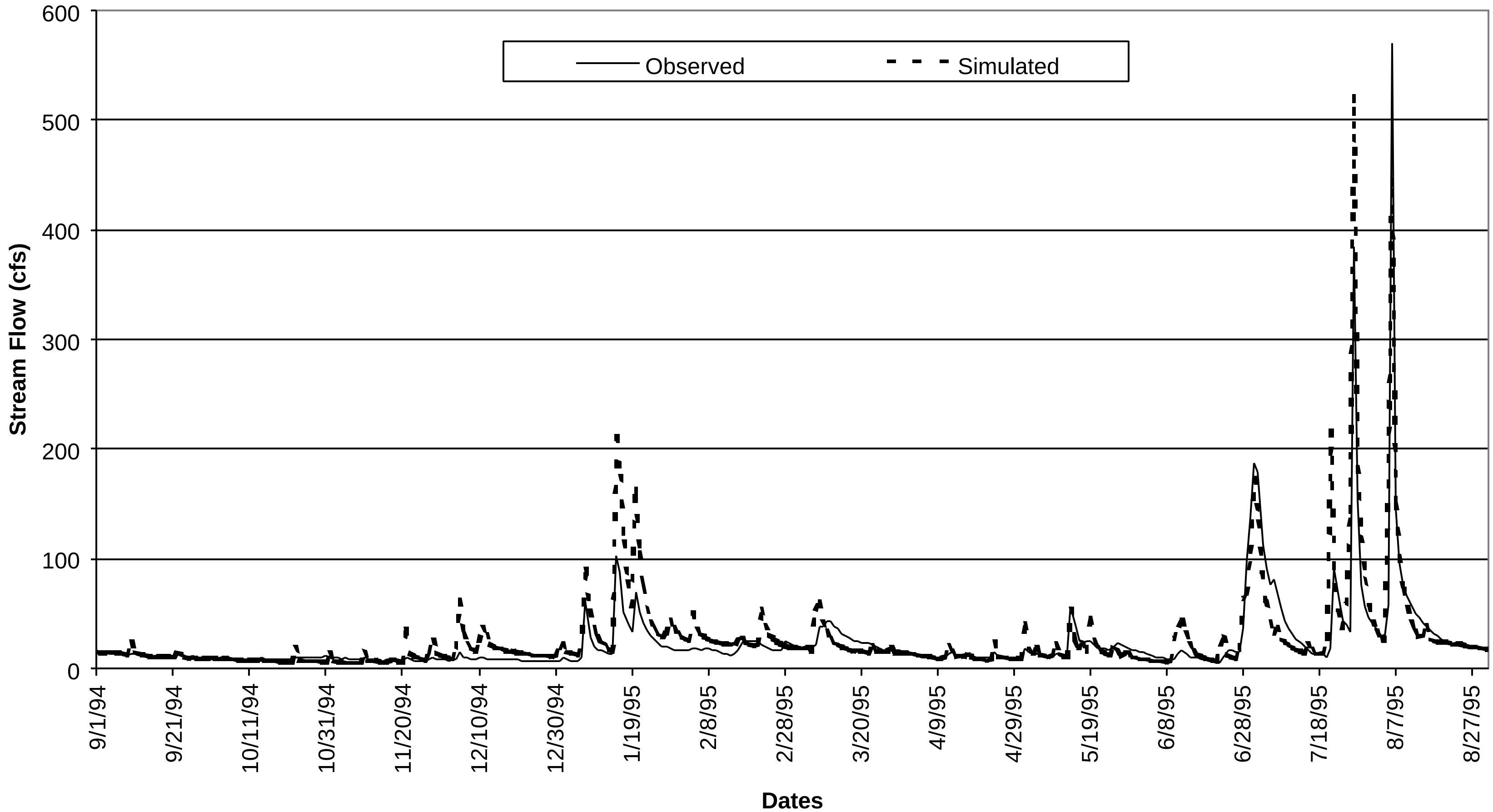

Figure 5.2. Simulated and observed stream flow for Linville Creek for a portion of the calibration period (Sept. 1, 1994 to August 31, 1995).

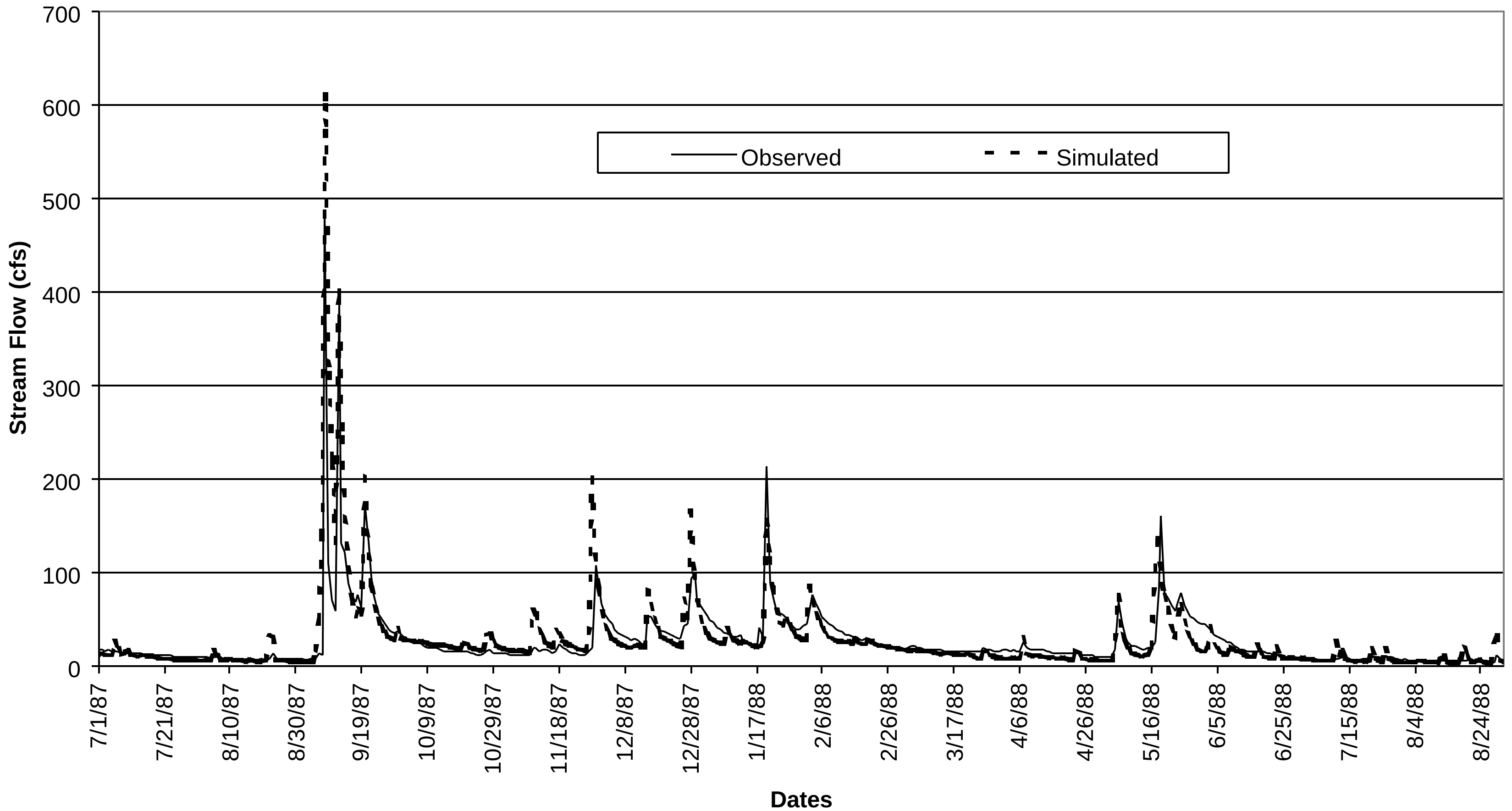

Figure 5.3. Simulated and observed stream flow for Linville Creek during the period of July 1, 1987 to July 31, 1988.

To test if the calibrated input data set for Linville Creek represents the hydrologic processes of other watersheds in the region, an additional validation run was conducted for the Muddy Creek watershed for the period of April 13, 1993 to June 30, 1995. As with Linville Creek, there was good agreement between the simulated and observed stream flow (Table 5.8). For the Muddy Creek validation, the total and summer (June – August) stream flows were excellent, but the winter (December – February) stream flow error exceeded the desired criterion of 10% error. In spite of the high winter stream flow error, the hydrology portion of the model was judged to be successfully validated because of the success of the calibrated data set with the longer Linville Creek validation period. In addition, the calibrated data set did a good job of representing summer flow conditions when the majority of the simulated water quality standards violations occur. The significance of the Muddy Creek winter storm flow error was also considered less significant because the climatic condition during the two winter periods simulated were considerably different from the average condition and was not representative of the long-term climatic patterns. The high percent error for the winter stream flow could also be attributed to errors in the precipitation data, which would be magnified because of the short duration of the validation period.

Table 5.8. Summary Values for Muddy Creek Validation Simulation.

Parameter	Simulated (in.)	Observed (in.)	Percent Error
Total stream flow	21.5	19.5	10.3%
Summer[a] stream flow	3.0	3.2	-6.3%

[a] June – August

In general, the validation results from both Linville and Muddy Creeks indicate that the calibrated model characterizes the hydrologic processes of the region reasonably well. Therefore, the calibrated parameters were assumed to provide a good first estimate of the parameters required to simulate the hydrology of the Dry River watershed for TMDL development purposes. As discussed later, the hydrology parameters had to be recalibrated when the calibrated hydrology parameters were used in the Dry River watershed simulation because the model tended to over-predict observed monthly runoff amounts during all seasons and particularly during the critical summer months.

Modeling the upper Dry River watershed

Since the upper Dry River was not impaired and is entirely forested, we modeled the upper Dry River watershed separately from the lower Dry River watershed. We then represented the time series outflow from the upper Dry River watershed as a point source inflow to the lower Dry River watershed (as was done with the Muddy Creek discharge). The hydrology parameters from the Linville Creek watershed calibration were used for the upper Dry River watershed simulation. These parameters were adjusted as follows to better represent the expected hydrologic response of this mountainous and forested watershed.

The INFILT parameter from the Linville Calibration (0.08 for forest) was decreased to 0.05 based on differences in the Hydrologic Soil Groups found in the upper Dry River watershed. Furthermore, the BASETP parameter was increased from 0.05 to 0.2 for the upper Dry River watershed. This value simulates the amount of potential ET that is satisfied by ET from riparian vegetation, which is expected to be high in heavily forested areas like the upper Dry River. Finally, the AGWRC value of 0.98 was decreased to 0.9 for the upper Dry River simulations based on our professional judgment. The AGWRC parameter controls the rate at which base flow recession decreases. One would expect the recession rate for a forested watershed with shallow soils and steep land slopes like upper Dry River to be faster than for the valley bottom forests in Linville Creek. The decrease in the AGWRC represents this expected difference.

Modeling the lower Dry River watershed

When the hydrology parameter set from the Linville and Muddy Creeks were applied to the lower Dry River watershed, comparison of the simulated daily flows and the observed monthly flow measurements revealed that the model tended to over-predict low flows at the lower Dry River monitoring site for which monthly flow estimates were available.

Consequently, model parameters were calibrated to better represent low flow conditions when water quality violations of the 30-day geometric mean standard were more common. Six hydrology parameters received additional calibration. The parameter DEEPFR (fraction of groundwater inflow entering deep groundwater) was increased from 0.19 to 0.6 and the interflow recession parameter, IRC was increased from 0.60 to 0.85.

Similarly, the interflow inflow parameter, INTFW, was increased from 2.2 to 5.0 and the soil infiltration capacity, INFILT, was increased from a range of 0.05 - 0.08 to 0.25. The lower zone nominal storage, LZSN, was increased from a range of 6 - 7 to 10, and the fraction of remaining ET satisfied from base flow, BASETP, was increased from 0.05 to 0.20. Detailed information justifying the INTFW and INFILT values used in the Dry River TMDL is included in Appendix F.

After adjusting the normal model parameters that are used to minimize low flows to their maximum suggested values, HSPF predicted that there would almost always be flow in the Honey Run and lower Dry River watersheds. Thus, additional calibration was required to simulate the qualitative observed extended dry periods in Honey Run and the portion of the lower Dry River upstream of Muddy Creek. We removed the remaining low flows by adding groundwater exits to the Honey Run reaches and the reaches of the lower Dry River above the confluence with Muddy Creek. Once the stage in these reaches dropped below a preset level, flow was diverted to the new groundwater exit (which did not return water to the watershed) and the flow in the stream became zero. This eliminated all flows below a predefined level. In this manner, flows less than 1.07 and 8 cfs were eliminated in the Honey Run and lower Dry River (above the confluence with Muddy Creek), respectively. This greatly improved low flow predictions and conformed to qualitative observations of the residents in the Dry River watershed.

The resulting simulated daily stream flow and the monthly flow measurements for Dry River are shown in Figures 5.4a and b. These simulations include the inflows from upper Dry River and Muddy Creek. Partitioning of the total flow indicated that surface flow (SURO), interflow (IFWO), and active groundwater (AGWO) accounted for 5.31%, 17.39%, and 77.29% of the flow, respectively. Generally, there is good agreement between the simulated stream flow and monthly observations. The calibration under-predicted one observed high flow value on Jan. 17, 1995 by an order of magnitude (166 versus 1170 cfs), but most other daily predictions were within a factor of two observed flows (Figure 5.4a). Based on the results presented Figures 5.4a and 5.4b, it can be concluded that the HSPF model adequately represents the hydrology of the Dry River.

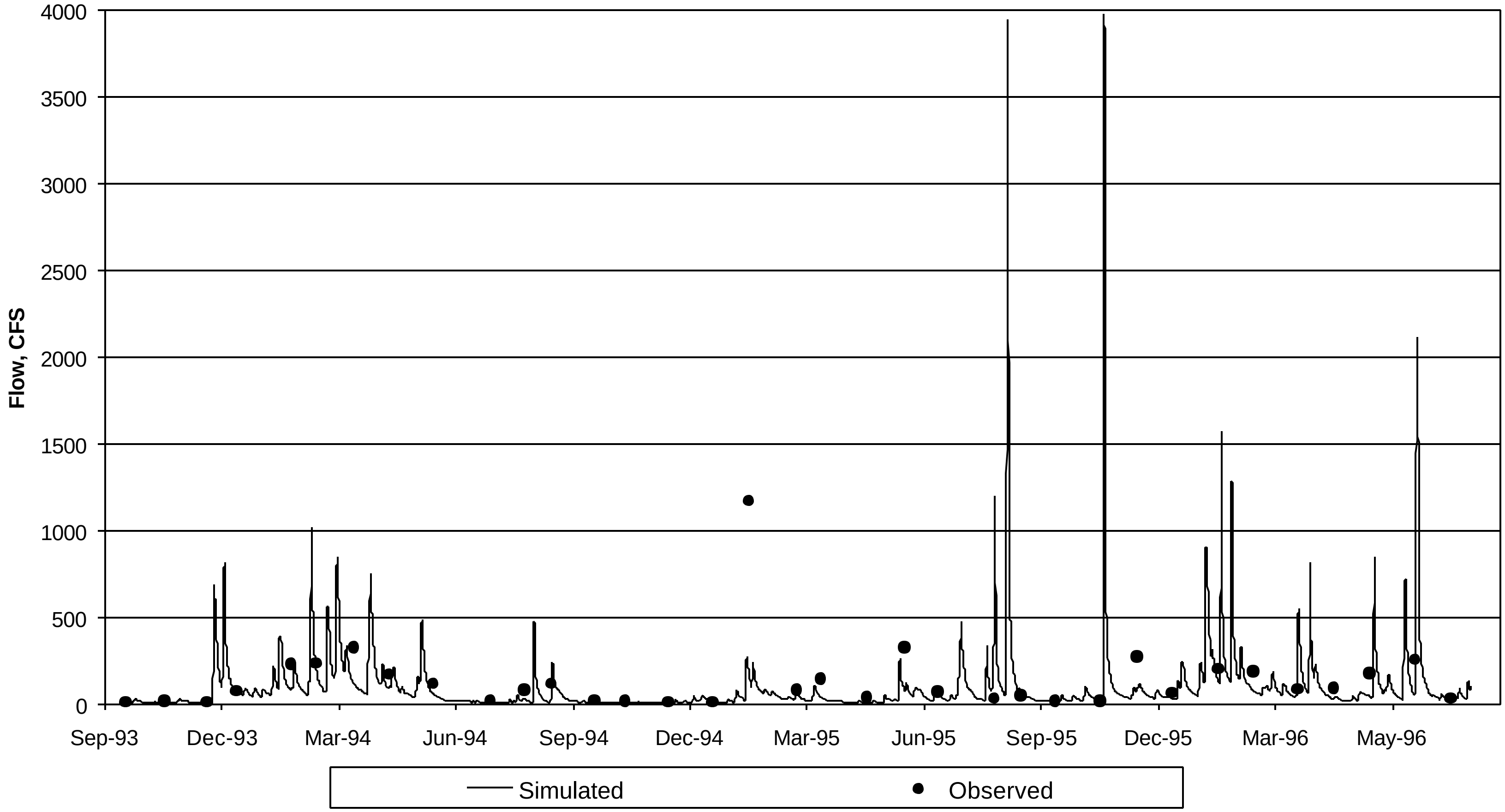

Figure 5.4a. Simulated average daily stream flow and monthly stream flow measurements for Dry River (high flow scale).

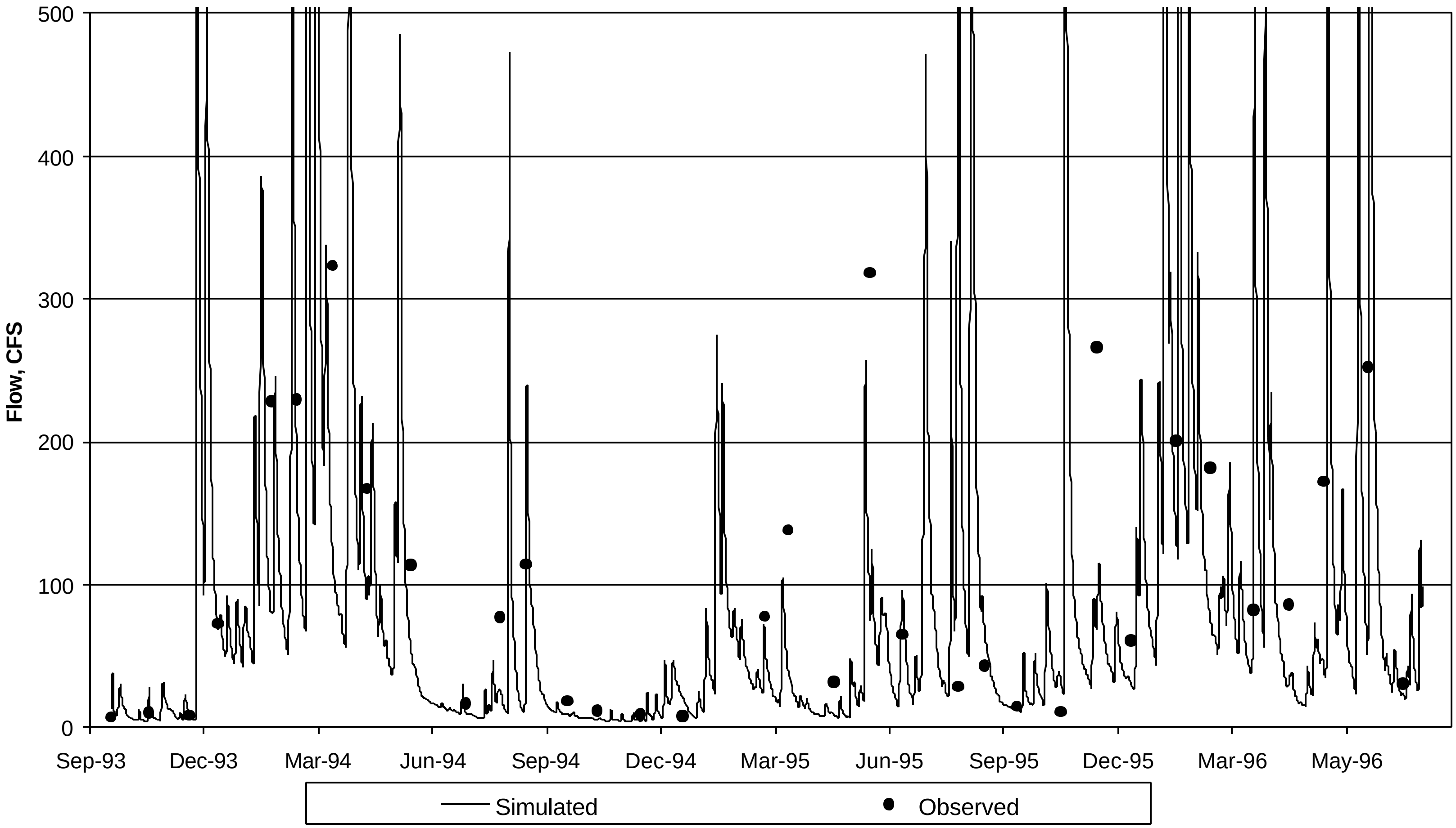

Figure 5.4b. Simulated average daily stream flow and monthly stream flow measurements for Dry River (lower flow scale).

5.5.2. Fecal coliform calibration for existing conditions

Procedure

After the hydrologic calibration and validation were completed, the water quality component of HSPF was calibrated. Sixty-four fecal coliform samples for the Dry River watershed were collected by VADEQ from September 1993 to December 1998. Since the complete meteorological data set only extended until July 1996, 35 samples (September 1993 – July 1996) were used for calibration. The accuracy of the simulations was measured visually using graphs of simulated and observed values. Further assessment of simulation accuracy beyond July 1996 was not feasible due to the lack of weather data. In the fecal coliform simulations, flows from the forested upper Dry River subwatershed, which was simulated as a point source, were assumed to have a background fecal coliform concentration of 30 cfu/100mL for natural forested watersheds as used in the Muddy Creek TMDL project (Muddy Creek TMDL Establishment Workgroup, 1999). Based on mean monthly flow and a background fecal coliform concentration of 30 cfu/100mL, monthly fecal coliform loads from the upper Dry River were calculated (Table 5.9) and applied as point source in simulating the lower Dry River. Fecal coliform concentrations for the Muddy Creek inflow to Dry River were obtained from times series developed as part of the Muddy Creek TMDL project (Muddy Creek TMDL Establishment Workgroup, 1999) and were supplied by VADCR.

Table 5.9. Monthly fecal coliform loading from the upper Dry River watershed

Month	Fecal coliform load (´ 10^9 cfu)
Jan	155.4
Feb	89.1
Mar	114.9
Apr	41.6
May	68.8
Jun	75.8
Jul	52.3
Aug	115.8
Sep	6.4
Oct	58.8
Nov	34.1
Dec	64.7
Total	**877.7**

Results

Given the similarities in agriculture and land use, HSPF fecal coliform parameters (Table 5.10) from the Mill Creek and Pleasant Run TMDL studies (Virginia Tech, 2000) were applied to lower Dry River watershed without adjustment. As shown in Figures 5.5a and b, there is considerable variation in the observed fecal coliform concentrations, which ranged from 5 to greater than 16,000 cfu/100mL. The observed data show that 40% of the observations are less than 100 cfu/100mL and 17% exceeded 2,000 cfu/100mL. The mean and median values of the observed values are 679 and 395 cfu/100mL, indicating that coliform concentrations are usually relatively low. The model under-predicted many of the observed high fecal coliform conditions (> 2,000 cfu/100mL), but attempts to improve predictions of high concentrations while maintaining good predictions of low and intermediate concentrations (<2,000 cfu/100 mL and 83% of the observations) were unsuccessful. The low and intermediate concentration predictions (<2,000 cfu/100 mL) were generally within a factor of one to five of observed values. Attempts to increase the accuracy of high concentration predictions resulted in gross over predictions of the low to intermediate fecal concentrations, which are more characteristic of the lower Dry River. Since the majority of the violations of the 30-day geometric mean standard occurred during low flow periods (late spring through summer as shown in Figure 6.2) when low and intermediate concentrations dominated, increased weight was given to the calibration of the low to intermediate concentration periods. Overall, there was good agreement between the simulated and observed fecal coliform concentration trends and the model is assumed to be sufficiently validated for TMDL development purposes.

Table 5.10. Fecal coliform parameters[a] used in the lower Dry River study

Module/sub-module	Parameter	Value
PERLND/PQUAL	WSQOP	2.4 in./h
	IOQC	1461 cfu/ft^3
	AOQC	1461 cfu/ft^3
	SQO	$10^9 – 10^{11}$ cfu/acre[b]
	POTFW	0 cfu/ton
	POTFS	0 cfu/ton
IMPLND/IQUAL	SQO	10^7 cfu/acre
	POTFW	0 cfu/ton
	WSQOP	2.4 in./h
RCHRES/GQUAL	FSTDEC	1.15 day^{-1}
	THFST	1.05

[a] See Lahlou et al. (1998) for description
[b] Function of land-use type

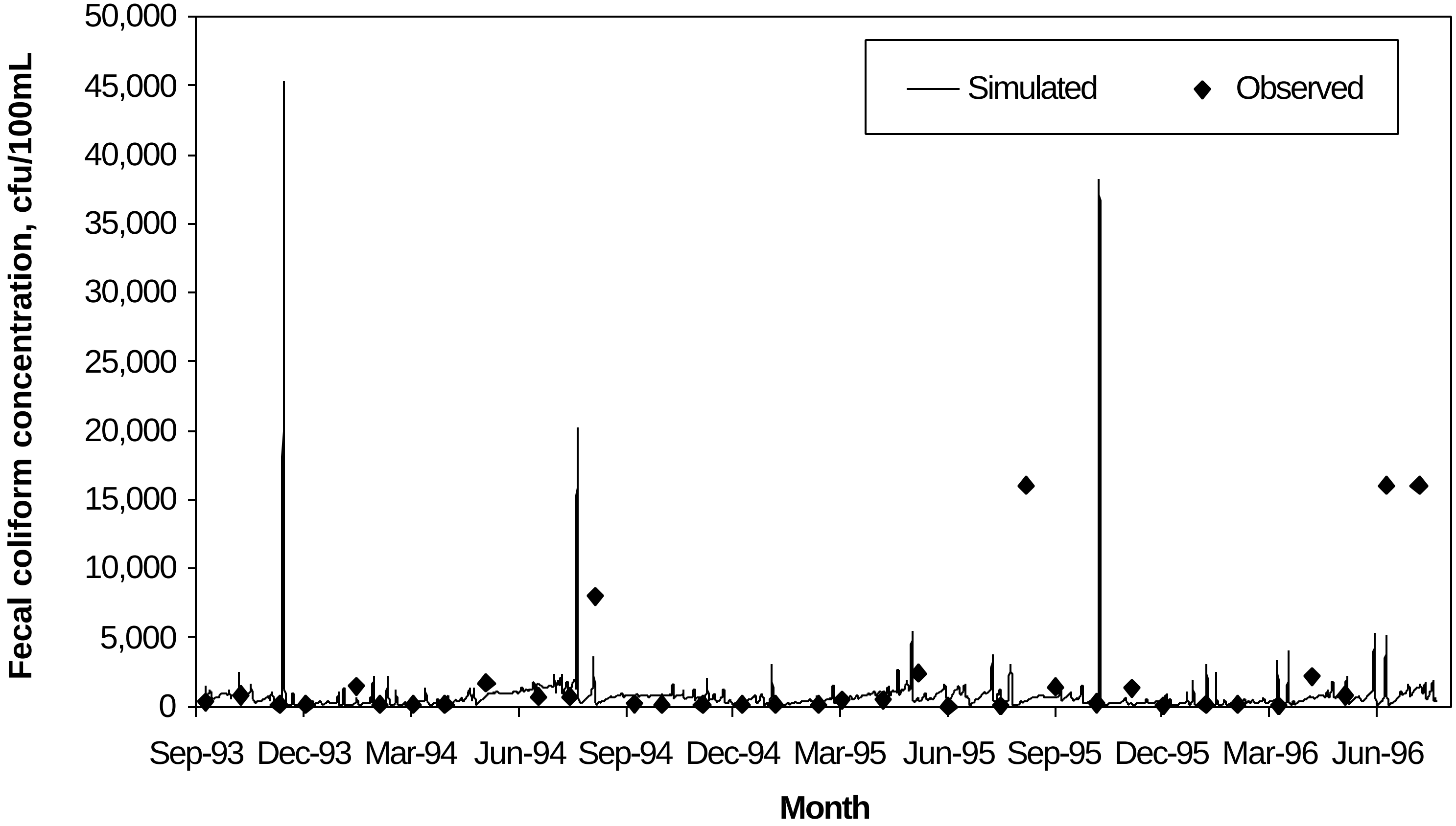

Figure 5.5a. Fecal coliform calibration for existing conditions for Dry River(high concentration scale).

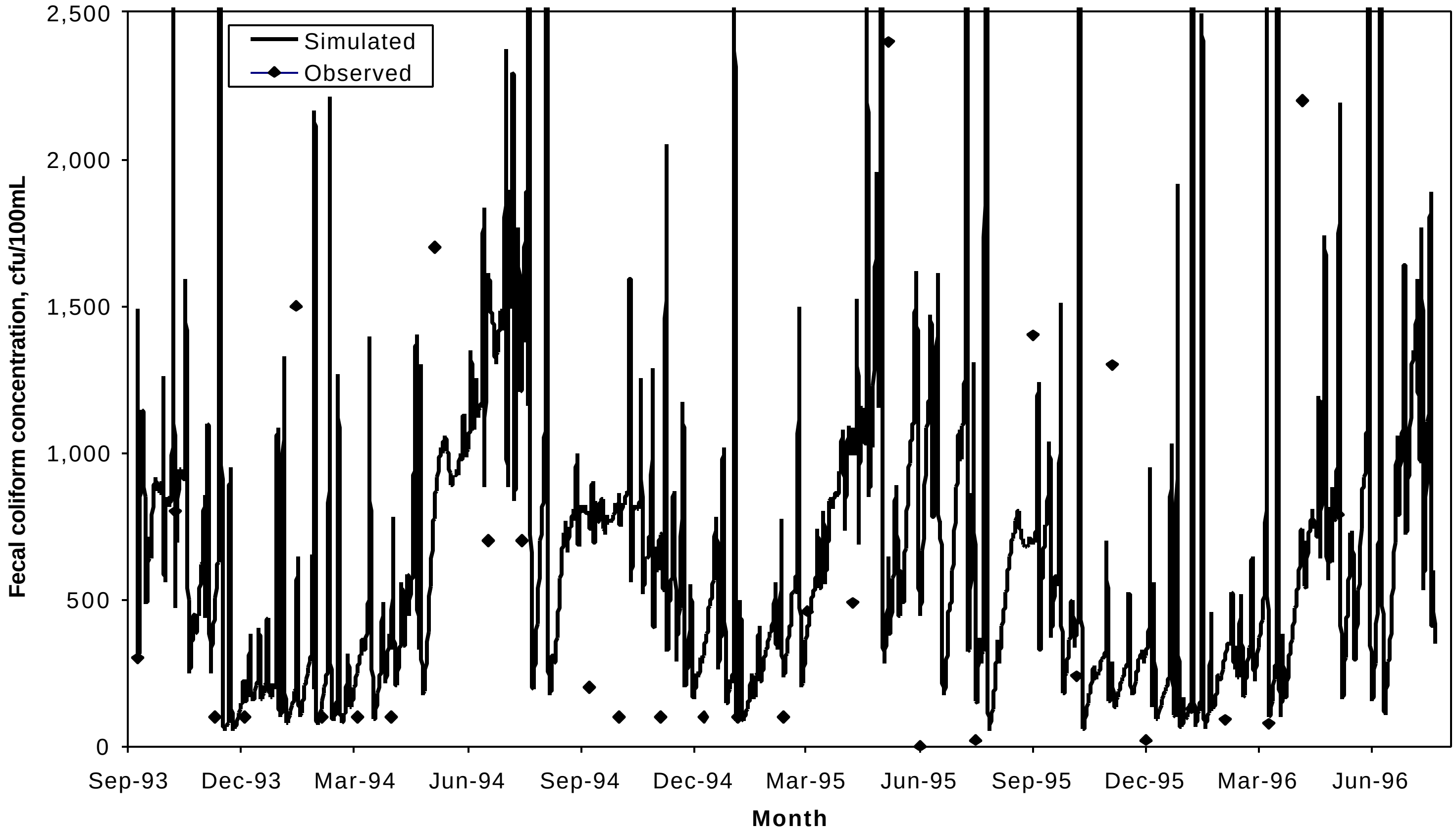

Figure 5.5b. Fecal coliform calibration for existing conditions for Dry River (lower concentration range).

6. LOAD ALLOCATIONS

6.1. Background

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The objective of the TMDL for lower Dry River was to determine what reductions in fecal coliform loadings from point and nonpoint sources are required to meet state water quality standards. The TMDL also considers the fecal coliform TMDL developed for Muddy Creek (Muddy Creek TMDL Establishment Workgroup, 1999). The state water quality standard for fecal coliform used in the development of the TMDL was the 30-day geometric mean standard of 200 cfu/100mL. The TMDL considers all sources contributing fecal coliform to Dry River. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [6.1]$$

where,

WLA = waste load allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = Margin of safety.

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (EPA, 1991). For the Dry River TMDL, a MOS of 5% was incorporated explicitly in the TMDL equation, in effect reducing the target fecal coliform concentration (30-day geometric mean) from 200 cfu/100mL to 190 cfu/100mL.

The time period selected for the load allocation study was September 20, 1993 to July 16, 1996, the same period for which observed data were available. This period was selected because it covers the period in which water quality violations were observed and it incorporates a wide range of hydrologic events including both low and high flow conditions.

6.2. Existing Conditions

Analyses of the simulation results for the existing conditions in the watershed for the period September 20, 1993 to July 16, 1996 (Table 6.1) show that fecal coliform loading from the Muddy Creek is responsible for an average of 61% of the mean daily fecal coliform concentration in the Dry River. Direct deposition of manure by cattle into the Dry River is the second major source of fecal coliform and is responsible for 36% of the mean daily fecal coliform concentration. The other sources, NPS loadings from pervious and impervious, combined, land segments, direct pipes, wildlife, and loadings from the upper Dry River watershed are responsible for less than 3.5% of the mean daily concentration. Direct deposits by cattle are a critical source, especially during dry weather conditions. During summer, each cattle that is on pasture with stream access, spends an estimated 3.5 hours in the stream (Table 4.3). Hence, of the 1,915 cattle on pastures with stream access, an equivalent of 279 cattle spend the entire day in the stream. Since 30% of the cattle in the stream defecate in the stream (Sec. 4.2), 84 cattle defecate in stream which amounts to 4.4% of the entire manure load produced by cattle on pastures with stream access. The fraction of manure directly deposited in the stream at other times of the year was lower, but still caused problems during extended dry weather periods.

Table 6.1. Relative contributions of different fecal coliform sources to the overall mean fecal coliform concentration for the existing conditions.

Fecal Coliform Source	Mean Daily Fecal Coliform Concentration Attributable to Source, cfu/100mL	Relative Contribution by Source Including Muddy Creek, %	Relative Contribution by Source Excluding Muddy Creek, %
All sources	726	100.0	100.0
Muddy Creek	441	60.7	0
Direct deposits by dairy and beef cattle to streams	262	36.1	91.9
NPS loadings from pervious and impervious land segments	11	1.5	3.9
Direct deposits by wildlife to streams	11	1.5	3.9
Direct pipes	1	0.1	0.3
upper Dry River	<1	<0.1	<0.1

6.3. Allocation Scenarios

Several allocation scenarios were evaluated to meet the 30-day geometric mean TMDL goal of 190 cfu/100mL. The first allocation scenario evaluated the contribution of FC from the inflow of Muddy Creek alone to Dry River. In this scenario, contributions from all other sources of fecal coliform loadings in the lower Dry River were turned off, except for fecal coliform entering from Muddy Creek (Figure 6.1).

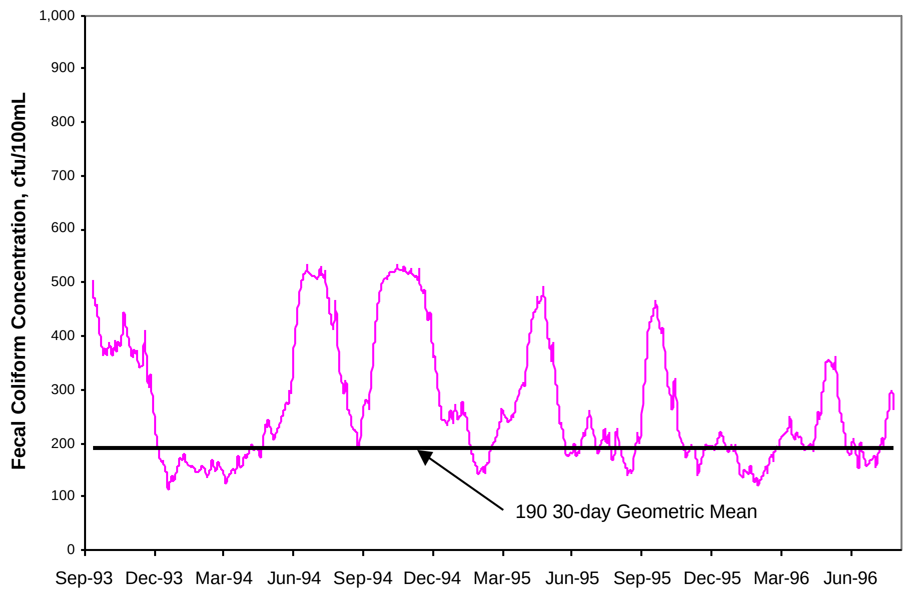

Figure 6.1. Simulated 30-day mean fecal coliform concentrations in Dry River assuming only existing Muddy Creek inflows. All other fecal coliform sources are excluded.

As shown in Figure 6.1, the fecal coliform loading from Muddy Creek alone causes fecal coliform concentrations to violate the 30-day geometric mean goal of 190 cfu/100mL in the Dry River. In fact, the 30-day geometric mean goal is exceeded 69% of the time and reaches a peak value of approximately 522 cfu/100mL. This implies that in developing a TMDL allocation plan for the Dry River, the fecal coliform contributions from Muddy Creek are critical and must be addressed. After consulting with VADCR, it was agreed that a TMDL allocation developed for Dry River would include the implementation of the Muddy Creek TMDL allocation plan. For all Dry River TMDL allocation scenarios, the inflow from Muddy Creek conformed to the recommended TMDL allocation specified in the Muddy Creek TMDL allocation plan. In other words, the Dry River TMDL allocation scenarios assume that the fecal coliform reductions required by the Muddy Creek TMDL are achieved. Even after implementation of the Muddy Creek TMDL allocation, the target 30-day geometric mean concentration of 190 cfu/100 mL is still exceeded, as shown in Figure 6.2. This indicates that the TMDL allocation plan for Dry River requires both the implementation of the Muddy Creek TMDL and the reduction of fecal coliform loadings to streams within the rest of the Dry River watershed.

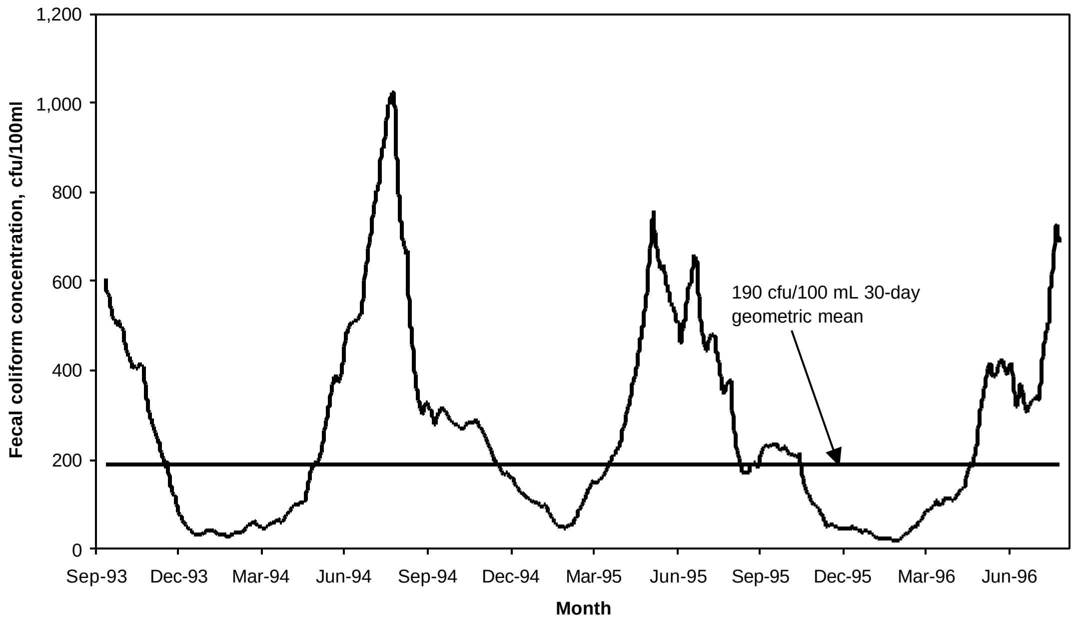

Figure 6.2. Simulated 30-day mean fecal coliform concentrations in the Dry River due to existing Dry River loads and TMDL implementation in Muddy Creek.

The results of selected TMDL scenarios are summarized in Table 6.2. Because direct deposition of manure by cattle into streams contributes over 92% of the existing load if Muddy Creek contributions are excluded (36% of the load if Muddy Creek is not excluded,see Table 6.1), all of the allocation scenarios considered for Dry River focus on reducing direct deposits by cattle. For all of the scenarios it is assumed that the straight pipe discharge to the stream from one milking parlor can be identified and eliminated.

Table 6.2. Fecal coliform TMDL allocation scenarios for the lower Dry River

Scenario Number	Percent reduction in loading from existing condition				
	Direct wildlife deposits	Direct cattle deposits	NPS from land segments	Milking parlor wash-off	Percentage of days with 30-day GM > 190 cfu/100mL
1	0	50	0	100	29.3
2	0	75	0	100	4.9
3	**0**	**84**	**0**	**100**	**0.0**
4	0	75	50	100	4.0

Scenario 3 meets the TMDL allocation requirement of no violations of the 190 cfu/100mL 30-day geometric mean goal (Table 6.2). Scenario 3 requires an 84% reduction in direct fecal coliform loading to the stream from cattle and no reduction in nonpoint sources (Table 6.3 and Table 6.4). It can be seen from Table 6.1 that the nonpoint sources in Dry River contribute a very small portion of the fecal coliform load to the Dry River. This is confirmed by scenario 4 (Table 6.2) in which a 50% reduction in nonpoint source loadings from land segments, in addition to 75% reductions in direct cattle deposits, only reduces violations of the 30-day geometric mean from 4.9 to 4.0% of the time. In contrast, an additional 25% reduction in direct deposits by cattle to streams reduces violations of the 30-day geometric mean from 29.3 to 4.9% of the time (Scenarios 1 and 2 in Table 6.2). Scenarios 1 through 3 (Table 6.2) emphasize the importance of cattle in streams as a source of fecal coliform loading, especially under low-flow conditions. For this reason, the focus was placed on reducing direct deposits from cattle in the streams in the Dry River. The 30-day geometric mean fecal coliform concentrations resulting from Scenario 3, as well as the existing conditions, are presented graphically in Figure 6.3.

Table 6.3. Annual nonpoint source loads from lower Dry River under existing conditions and corresponding reductions for TMDL allocation scenario 3.

Land-use category /Source	Existing conditions		Allocation scenario	
	Existing load (× 10^{12} cfu)	Percent of total load to stream from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	67.5	20.2	67.5	0.0
Pasture 1	119.9	35.9	119.9	0.0
Pasture 2	14.7	4.4	14.7	0.0
Pasture 3	111.7	33.5	111.7	0.0
Loafing Lots	2.1	0.6	2.1	0.0
Rural Residential	8.6	2.6	8.6	0.0
Farmstead	5.3	1.6	5.3	0.0
Forest	3.9	1.2	3.9	0.0
Total[a]	333.7	100.0	333.7	0.0

[a] There is no loading from urban residential land-use type

Table 6.4. Annual direct nonpoint source loads from lower Dry River under existing conditions and corresponding reductions for TMDL allocation scenario 3.

Source	Existing conditions load (× 10^{12} cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
Cattle in streams	182.4	98.1	29.2	84.0
Wildlife in Streams	2.4	1.3	2.4	0.0
Milking parlor wash-off	1.1	0.6	0	100.0
Total	185.9	100.0	31.6	83.0

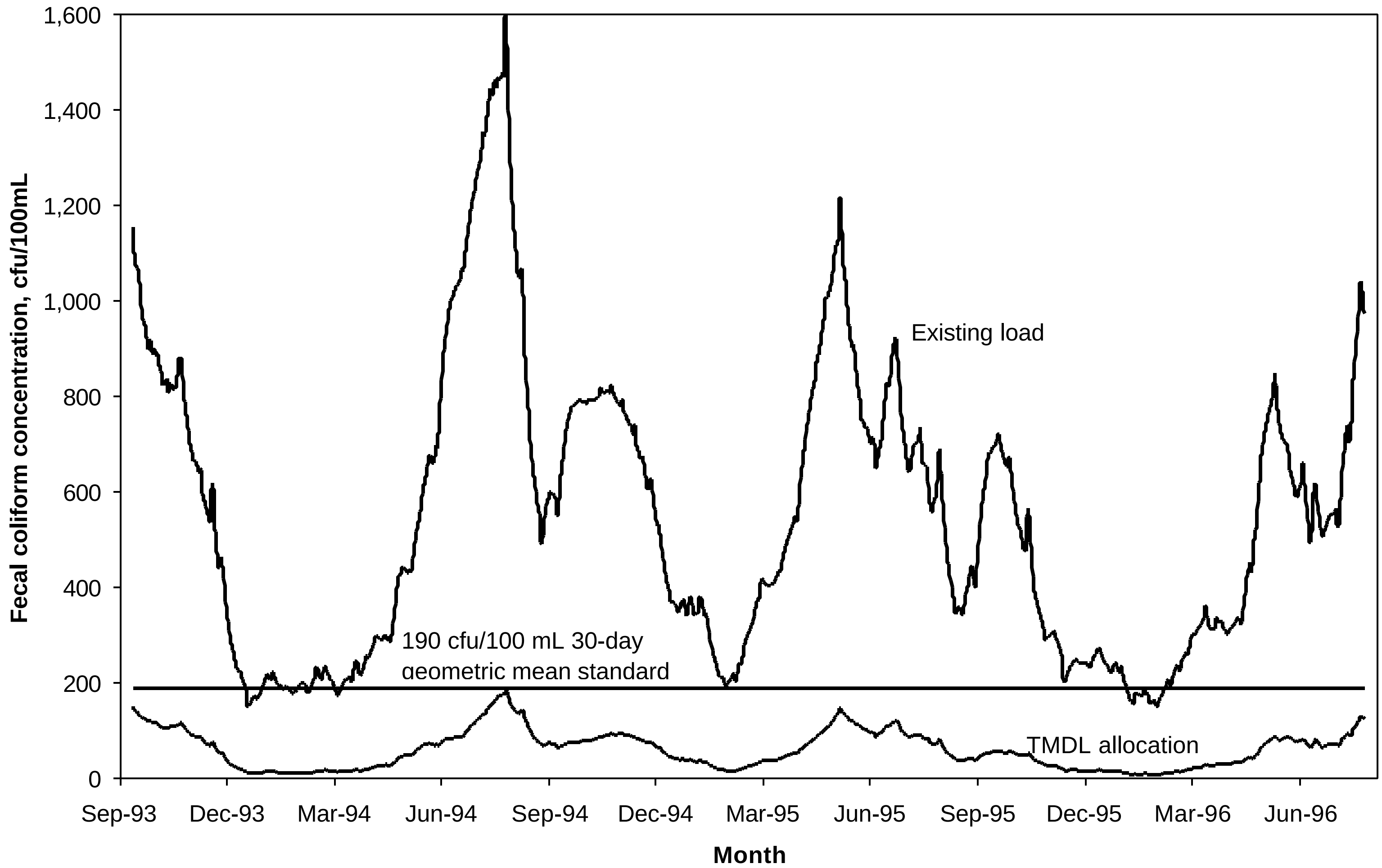

Figure 6.3. Successful TMDL allocation, 190 cfu/100mL 30-day geometric mean goal, and existing conditions (Allocation Scenario 3 from Table 6.2).

6.4. Summary of TMDL Allocation Plan

A TMDL for fecal coliform has been developed for Dry River. The TMDL addresses the following issues.

1. The TMDL meets the water quality standard based on the 30-day geometric mean. After the plan is fully implemented, the 30-day geometric mean of fecal coliform concentration will not exceed 190 cfu/100 mL.
2. The TMDL accounts for all fecal coliform sources (human-related and wildlife).
3. A margin of safety (MOS) of 5% was incorporated to ensure compliance of the geometric mean standard upon full plan implementation.
4. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Dry River watershed, low flow conditions were found to be the environmental condition most likely to cause a violation of the 30-day geometric mean; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.
5. Both the flow regime and fecal coliform loadings are seasonal, with higher loadings and in-stream concentrations during the summer than in the winter. The TMDL accounts for these seasonal effects.
6. The TMDL allocation plan that met the 30-day geometric mean water quality goal of 190 cfu/100mL, required an 84% reduction in direct deposits of cattle manure to streams in the lower Dry River watershed and the implementation of the TMDL developed for Muddy Creek. Using Equation [6.1] and based on the TMDL allocation scenarios (Scenario 3), a summary of fecal coliform TMDL for lower Dry River is presented in Table 6.5.

Table 6.5. Annual fecal coliform allocation (cfu/year) used for developing the fecal coliform TMDL.

Parameter	S WLA	S LA	MOS[a]	TMDL
Muddy Creek[b]	0.30×10^{12}	8.35×10^{12}	0.46×10^{12}	9.11×10^{12}
upper Dry River	0	0.88×10^{12}	0.05×10^{12}	0.93×10^{12}
lower Dry River[c]	0	365.30×10^{12}	19.23×10^{12}	384.53×10^{12}
Total	0.30×10^{12}	374.53×10^{12}	19.74×10^{12}	394.57×10^{12}

[a] Five percent of the TMDL
[b] After TMDL implementation (Muddy Creek TMDL Establishment Workgroup, 1999)
[c] Excluding Muddy Creek loading

7. IMPLEMENTATION

7.1. Follow-up Monitoring

The existing monitoring station will be maintained by VADEQ during the TMDL implementation process. The station (1BDUR000.02) was established in September of 1993. VADEQ and VADCR will continue to use data from this monitoring station for evaluating reductions in fecal bacteria counts and the effectiveness of the TMDL in attainment of water quality standards.

Monthly sampling for fecal coliform bacteria will continue at 1BDUR000.02 until the violation rate of Virginia's fecal coliform standard, 1,000 cfu/100 mL, is reduced to 10% or less. After this reduction in the fecal coliform violation rate is verified, the monitoring frequency for this parameter will be increased to two or more samples within a 30-day period. This sampling frequency is needed to provide the water quality data needed for evaluation and verification that the TMDL will attain and maintain Virginia's water quality standard, the geometric mean of 200 cfu/100 mL.

7.2. TMDL Implementation Process

The goal of this TMDL is to develop a plan, which will lead to expeditious attainment of the water quality standards. The first step in this process was to develop an implementable TMDL. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL.

Section 303(d) of the Clean Water Act and USEPA's 303(d) regulation (USEPA, 1998a) do not specify implementation mechanisms for TMDLs. However, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act directs VADEQ to develop a plan for the expeditious implementation of TMDLs.

Virginia DEQ plans to incorporate TMDL implementation plans as part of the 303(e) Water Quality Management Plans (WQMP). In response to the recent USEPA/VADEQ Memorandum of Understanding, VADEQ submitted a Continuous Planning Process to USEPA in which Virginia commits to updating the WQMPs, which will be the repository of TMDLs and the implementation plans. Each implementation plan will contain a reasonable assurance section that details the availability of funds for implementation of voluntary actions.

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration.

Watershed stakeholders will have opportunities to provide input and to participate in development of the implementation plan, with support from regional and local offices of VADEQ, VADCR and other participating assistance agencies

In order to avoid over-implementation in case the model was overly conservative or the applicable water quality standard changes, implementation of best management practices (BMPs) in the watersheds will occur in phases. The benefit of phased implementation is that as stream monitoring continues to occur, accurate measurements of progress being achieved will be recorded. This approach provides a measure of quality control, given the uncertainties which exist in the developed TMDL model. The target for the first phase of implementation will be 10% violation of the 1,000 cfu/100 mL instantaneous standard. Focusing the first phase on the instantaneous standard supports the phased monitoring approach proposed in paragraph 7.1 and is parallel to the Muddy Creek TMDL, which is instrumental to the full implementation of the Dry River TMDL.

7.3. Phase 1 Implementation Scenario

The goal of the Phase 1 Allocation Scenario was to determine the fecal coliform loading reductions that are required to reduce violations of the instantaneous 1,000 cfu/100mL water quality standard to less than 10 percent. Many of the scenarios considered reduced violations to less than 10% (Table 7.1). A prime factor considered in these scenarios was the possible loading reductions from Muddy Creek. Three loadings reduction scenarios from Muddy Creek were considered: full TMDL implementation, Phase 1 Implementation, and no implementation (existing conditions). As shown in Table 7.1, except Scenario 5, all other scenarios considered meet the Phase 1 implementation plan goal of less than 10% violation of the 1,000 cfu/100 mL instantaneous standard. Implementation of either the Muddy Creek TMDL Allocation or the Muddy Creek Phase I Implementation Plan reduces violations of the 1,000 cfu/100 mL instantaneous standard to less than 3.0% of the time without any reductions in fecal coliform loads in Dry River. Scenarios 4, 5, and 6 are based on the assertion that neither the Muddy Creek TMDL Allocation nor the Muddy Creek Phase I Plan is implemented. In other words, existing conditions for Muddy Creek are assumed.

Table 7.1. Allocation scenarios for Phase I TMDL implementation.

Scenario Number	Percent reduction in loading from existing condition					
	Direct wildlife deposits	Direct cattle deposits	NPS from land segments	Milking parlor wash-off	Status of[a] Muddy Creek	Percentage of days with FC Conc > 1,000 cfu/100mL
1	0	0	0	100	A	2.7
2	0	0	0	100	B	2.8
3	0	75	0	100	A	0.3
4	0	75	50	100	C	4.8
5	0	10	0	100	C	14.0
6	**0**	**28**	**0**	**100**	**C**	**9.8**

[a] A - Full Implementation of TMDL
B - Phase I Implementation
C - Existing Conditions

The resulting scenario selected for the Dry River Phase 1 Implementation Plan (Scenario 6) requires no reductions in fecal coliform loadings from nonpoint sources (Table 7.2). Phase 1 implementation requires a 28% reduction in direct deposits of manure to streams by cattle and elimination of all straight pipes from milking parlors (Table 7.3). Fecal coliform concentrations resulting from Scenario 6 implementation are presented graphically in Figure 7.1.

Table 7.2. Annual nonpoint source load reductions for Phase 1 TMDL implementation scenario (Scenario 6).

Land-use Category	Existing conditions: Existing load (× 10^{12} cfu)	Existing conditions: Percent of total load to stream from nonpoint sources	Allocation scenario: TMDL nonpoint source allocation load (× 10^{12} cfu)	Allocation scenario: Percent reduction from existing load
Cropland	67.5	20.2	67.5	0.0
Pasture 1	119.9	35.9	121.3	0.0
Pasture 2	14.7	4.4	14.7	0.0
Pasture 3	111.7	33.5	111.7	0.0
Loafing Lots	2.1	0.6	2.1	0.0
Rural Residential	8.6	2.6	8.6	0.0
Farmstead	5.3	1.6	5.3	0.0
Forest	3.9	1.2	3.9	0.0
Total[a]	333.7	100.0	333.7	0.0

[a] There is no loading from urban residential land-use type

Table 7.3. Annual direct nonpoint source load reductions for Phase 1 TMDL implementation scenario (Scenario 6).

Source	Existing conditions load (× 10^{12} cfu)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing loads
Cattle in streams	182.4	98.1	131.3	28.0
Wildlife in Streams	2.4	1.3	2.4	0.0
Milking parlor wash-off	1.1	0.6	0.0	100.0
Total	185.9	100.0	133.7	28.1

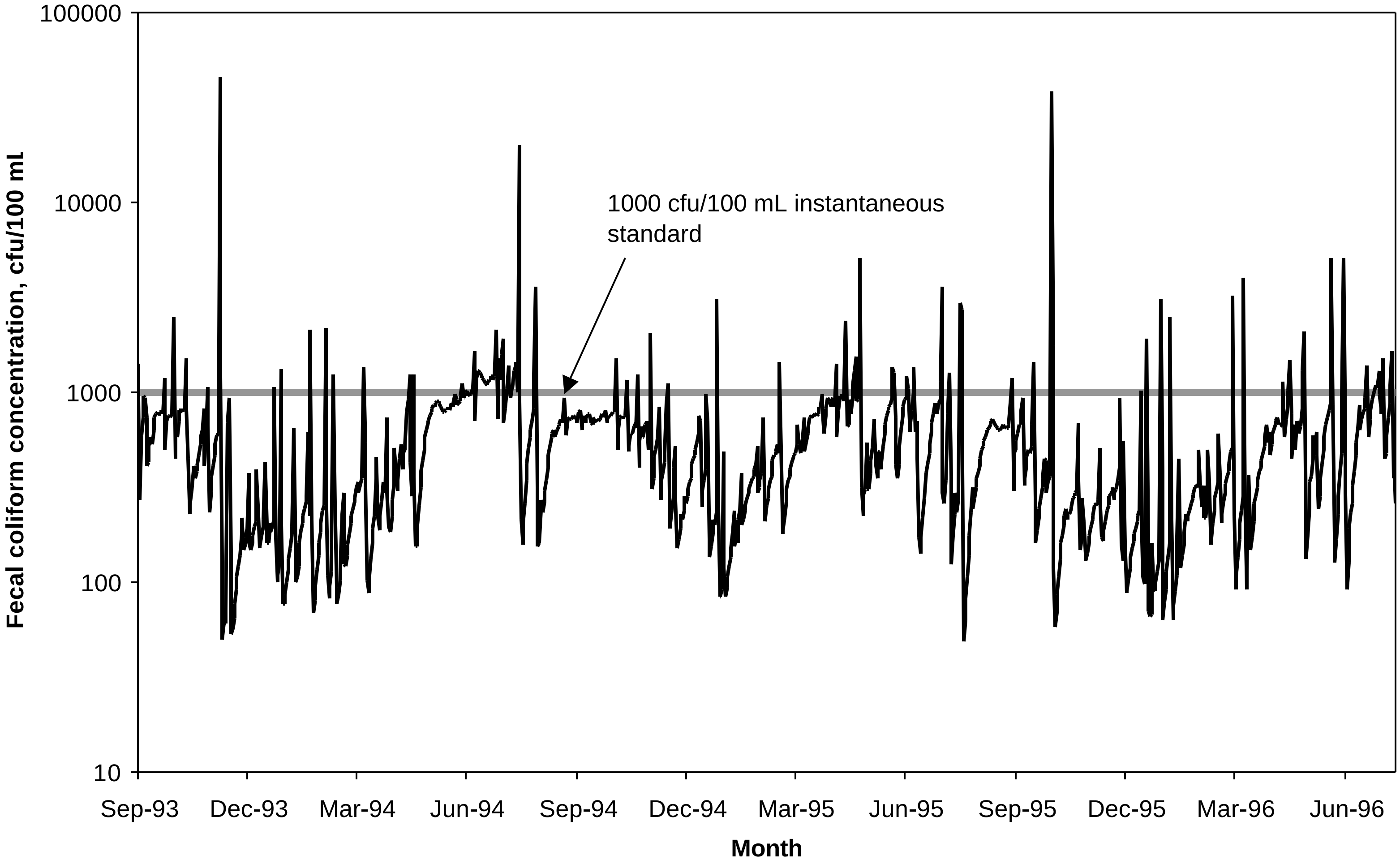

Figure 7.1. Phase I TMDL implementation scenario

7.4. Public Participation

The first public meeting, held in Dayton, VA on 9 December 1999 to discuss the development of the TMDL, was public noticed on 3 November 1999 in the Virginia Register. Letters announcing the meeting were also sent to stakeholders in the watersheds, including the Shenandoah Pure Water 2000 Forum, the Friends of the North River, the VA State Dairymen's Association, the VA Poultry Federation, the Rockingham Farm Bureau, the Rockingham County Administrator and the Rockingham County Planning Director. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 12 people attended the meeting. The public comment period ended on 21 January 2000. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA.

The second public meeting, held in Dayton, VA on 20 January 2000 to discuss the hydrologic calibration and input data for the TMDL, was public noticed on 14 December 1999 in the Virginia Register. Copies of the presentation materials and of the Q&A summary from the previous meeting were available for public distribution at the meeting. Approximately 10 people attended the meeting. The public comment period ended on 21 February 2000. A summary of the questions and answers discussed at the meeting was prepared and, together with subsequently received written comments, is located at the DEQ Valley Regional Office in Harrisonburg, VA.

The third public meeting, held in Dayton on 28 March 2000 to discuss the draft TMDL, was public noticed on 13 March 2000 in the Virginia Register. Also, approximately 300 notification letters with information about the event were sent to landowners in the watershed based on a list compiled by the Rockingham County Farm Bureau. Copies of the draft TMDL were available for public distribution at the time of public notice and at the meeting. Approximately 50 people attended the meeting. The public comment period ended on 11 April 2000. No written comments were submitted by the general public.

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GLOSSARY

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH)

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\overline{x}_g$, is expressed as:

$$\overline{x}_g = \sqrt[n]{x_1 \times x_2 \times \ldots \times x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of land-use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent (sludge) that remains after decomposition of the solids by bacteria in the tank; must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

APPENDIX A

Sample calculation: distribution of dairy cattle in DRR-A during January

Sample calculation: distribution of dairy cattle in DRR-A during January

(Note: For more detailed information, consult the spreadsheet fc_drr-a1.xls. Also, due to rounding, the numbers may not add up.)

1. Breakdown of the dairy herd as presented in Sec. 4.2.1 is 42% milk cows, 8% dry cows, and 50% heifers.

   Dairy cattle population = 1700.0
   Milk cow population = 1700 * (42%) = 714.0
   Dry cow population = 1700 * (8%) = 136.0
   Heifer population = 1700 * (50%) = 850.0

2. During January, milk cows, dry cows, and heifers are confined 75, 40, and 40% of the time, respectively (Table 4.3)

   Milk cows in confinement = 714 * (75%) = 535.5
   Dry cows in confinement = 136 * (40%) = 54.4
   Heifers in confinement = 850 * (40%) = 340.0
   All dairy cows in confinement = 535.5 + 54.4 + 340.0 = 929.9

3. When not confined, milk cows spend 25% time in the loafing lot. However, since one out of 10 diary operations has a loafing lot (Table 4.2), fewer milk cows are present in the loafing lot. Dry cows and heifers do not have access to loafing lot.

   Milk cows in loafing lot = (714 – 535.5)*(25%)*(1/10) = 4.5

4. Cattle in pastures and stream are calculated by subtracting cattle in confinement (Step 2) and in loafing lots (Step 3) from total cattle population (Step 1).

   Milk cows on pastures and streams = 714.0 – 535.5 – 4.5 = 174.0
   Dry cows on pastures and streams = 136.0 – 54.4 = 81.6
   Heifers on pastures and streams = 850.0 – 340.0 = 510.0

5. Total pasture acreage is 484.1 acres with pastures 1, 2, and 3 occupying 55.6%, 11.4%, and 33.0%, respectively (Table 3.2). The stocking densities in pastures 1, 2, and 3 are 1, 2, and 4, respectively (Sec. 4.2.1). Based upon the stocking density, relative stocking densities in pastures 1, 2, and 3 are 1/7, 2/7, and 4/7, respectively.

   Percent cattle in all pasture 1
   = (55.6%)*(1/7)/[(55.6%)*(1/7)+(11.4%)*(2/7) +(33.0%)*(4/7)] = 26.5
   Percent cattle in all pasture 2
   = (11.4%)*(2/7)/[(55.6%)*(1/7)+(11.4%)*(2/7) +(33.0%)*(4/7)] = 10.9
   Percent cattle in all pasture 3
   = 174*(33.0%)*(4/7)/[(55.6%)*(1/7)+(11.4%)*(2/7) +(33.0%)*(4/7)] = 62.6

6. Percentage acreage of pastures 1, 2, and 3 with access to stream are 0.9%, 65.1%, and 16.0%, respectively (Table 4.4). Use the percent Cattle in each pasture (step 5) to estimate percent cattle with access to stream:

   [(26.5%*0.9%)+(10.9%*65.1%)+(62.6%*16.0%)] = 17.3%

7. Cattle with access to streams are calculated as follow.

   Milk cows on pastures with stream access = 174*17.3% = 30.2
   Dry cows on pastures with stream access = 81.6*17.3%= 14.2
   Heifers on pastures with stream access = 510*17.3% = 88.4

8. Numbers of cattle in an around streams is calculated by multiplying cattle on pasture with stream access with the number of hours each cattle spends in the stream (Table 4.3). Cattle with stream access calculated in Step 7 are required.

   Milk cows in and around streams = 30.2*(0.5/24) = 0.6
   Dry cows in and around streams = 14.2*(0.5/24) = 0.3
   Milk cows in and around streams = 88.4*(0.5/24) = 1.8

9. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Sec. 4.2.1). Cattle in and around stream calculated in Step 8 are required.

   Milk cows defecating in streams = 0.6*30% = 0.2
   Dry cows defecating in streams = 0.3*30% = 0.1
   Heifers defecating in streams = 1.8*30% = 0.6

10. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pastures is calculated by subtracting the number of cattle defecating in the stream (Step 9) from number of cattle in pasture and stream (Step 4). To obtain the number of cattle in each pasture category, the number of cattle in all pastures is multiplied by the percent of cattle in that pasture category (Step 5).

    Milk cows defecating on pasture 1 = (174.0 – 0.2)*26.5% = 46.0
    Milk cows defecating on pasture 2 = (174.0 – 0.2)*10.9% = 18.9
    Milk cows defecating on pasture 3 = (174.0 – 0.2)*62.6% = 109.0
    Dry cows defecating on pasture 1 = (81.6 – 0.1)*26.5% = 21.6
    Dry cows defecating on pasture 2 = (81.6 – 0.1)*10.9% = 8.9
    Dry cows defecating on pasture 3 = (81.6 – 0.1)*62.6% = 51.1
    Heifers defecating on pasture 1 = (510.0 – 1.8)*26.5% = 134.8
    Heifers defecating on pasture 2 = (510.0 – 1.8)*10.9% = 55.3
    Heifers defecating on pasture 3 = (510.0 – 1.8)*62.6% = 319.3

APPENDIX B

Weather Data Preparation

Weather Data Preparation

Summary

A weather data file for providing the weather data inputs into the HSPF Model was created for the period September 1984 through July 1996 using the WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), total daily solar radiation (langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Dale Enterprise, Rockingham Co., Virginia; data from three other NCDC stations were also used. Daily solar radiation data was generated using CLIGEN[1]. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. The raw data were retained in the WDM file since WDMUtil does not have provision for deleting such data; such data can only be overwritten.

Raw data collection and processing

Weather data in the variable length format were obtained from the NCDC's weather stations in Dale Enterprise, VA (Lat./Long. 38.5N/78.9W, elevation 1400 ft); Timberville, VA (Lat./Long. 38.7N/78.7W, elevation 1001 ft); Lynchburg Airport, VA (Lat./Long. 37.3N/79.2W, elevation 940 ft); and Elkins Airport, WV (Lat./Long. 38.9N/79.9W, elevation 1948 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. While data for all other parameters were available for the September 1984 through December 1997 period, percent sun data were only available until July 1996. Hence, the weather WDM file was prepared for the September 1984 through July 1996 period. In the following pages, the procedures used to process the raw data to obtain finished data required for preparing the WDM file are described.

1. <u>Hourly precipitation</u>

   Hourly precipitation (PREC) data were purchased from the NCDC for Dale Enterprise for the period 1984 through 1998 in variable length format. Data in variable length format became available online and free of charge beginning mid-November, 1999. The file obtained from NCDC required modifications before it could be read by WDMUtil. First, the first four columns in each line that indicated the line width were removed with a text editor. Second, the unit of the PREC depth was changed to HI (hundredths of an inch) from HT (Note: the file should have the correct units in at least the first line of record). Finally, the file was renamed as an NCD file and was successfully read by WDMUtil.

The PREC record for the September 1984 through July 1996 period (4352 days) was missing 220 days of hourly precipitation data. Daily precipitation (PRECD) data collected by the NCDC's weather station at Dale Enterprise obtained for that period, was reported as the total depth of precipitation occurring during the past 24 hours as reported at 7 a.m.

The possibility of using a precipitation disaggregation program was considered. Such programs require a complete hourly record for a neighboring (template) station in addition to PRECD for the site. The station closest to Dale Enterprise collecting hourly precipitation data is the Staunton Sewage Plant (SSP) (Lat./Long. 38.2N/79.1W, elevation 1640 ft) located 21 miles to the south of Dale Enterprise. However, since the SSP data had missing records for many months, this option was discarded. Hence, the following options were used to fill in the missing hourly data.

a) Daily precipitation depth measured at Dale Enterprise was disaggregated into hourly values based on the hourly precipitation distribution observed at the SSP.
b) However, there were precipitation events in Dale Enterprise, as observed in the PRECD record that, either did not occur in SSP or the SSP records were missing for those periods. The following steps were taken to disaggregate such precipitation events.
    (i) If the total depth of precipitation was less than or equal to 0.2 in., the entire event was assumed to have occurred during the 6:00-7:00 p.m. hour of the previous day.
    (ii) For PRECD greater than 0.2 in., the raw PREC data file for DE was examined for that day (Note: If the raw PREC data is missing even 1 h of data as indicated by a missing depth value and an incomplete daily depth, WDMUtil will report a day with missing data). If no more than 2 h of data were missing, the difference between PRECD depth and the total incomplete depth record was assigned equally to the missing hours or in full if only one hour of data was missing.
    (iii) When PRECD exceeded 0.2 in. and raw PREC data file for DE indicated more than 2 h of missing data, the flow observed in Linville Creek was considered for disaggregating daily into hourly precipitation values. The flow data for Linville Creek data was used because it provided the longest period of record compared with flow records for other streams in that area. Since the flow data also account for watershed response to previous events and seasonality (e.g., thunderstorms), such an approach was considered to be appropriate.

Table A.1 provides a summary of the number of days when either option a or c was used. For those days when there were multiple precipitation events and when the same option could not be applied to all the events, multiple options were used (Note: no more than two options were used on a single day). For such days, the option used for the greater precipitation depth is listed.

Table A.1. Summary of number of days requiring disaggregation or no disaggregation

Option	Number of days
Option a: Used SSP PREC as a guide to disaggregate DE PRECD	143
Option b(i): For events = 0.2 in., assigned to single hour	31
Option b(ii): Used raw PREC data and PRECD data	21
Option b(iii): Used flow data	25
No processing required	4132

2. Temperature
Separate daily maximum temperature (TMAX) and daily minimum temperature (TMIN) files in variable length format were obtained from NCDC. Spurious data fields (e.g., 32 data fields for a month with 31 days) tagged in the TMAX variable length format file, were deleted. The TMAX data file had six days of missing data. The TMIN file did not have missing values. Both the TMAX and TMIN values for the six days were filled in with Timberville data. In each file (TMAX or TMIN), the first four columns in each line were deleted and the modified file was saved as an NCD file. Since daily average dew point temperature (DPTP) is not measured at Dale Enterprise, TMIN was used as DPTP, as recommended in the BASINS documentation. The TMIN NCD file was modified by replacing TMIN by DPTP and saved as a DPTP NCD file. All three files (TMAX, TMIN, and DPTP) were successfully read into WDMUtil. The DISAGGREGATE function in WDMUtil was used to develop hourly air temperature (ATEM) for the modeling period from TMAX and TMIN. Similarly, the DISAGGREGATE function was used to calculate hourly dew point temperature (DEWP) from DPTP.

3. Average daily wind speed
Since average daily wind speed (DWND) is not measured by the NCDC's weather station at Dale Enterprise, DWND data was obtained for NCDC's station at Elkins Airport, the closest location to Dale Enterprise where DWND is recorded. The variable length format file received from NCDC gave average daily wind speed in TL (tenths of mi./h). Since the file also contained the units of TK (tenths of knot/h), the file required modification to express the units only in TL. Also, editing was performed to remove one spurious data field. However, it was observed that WDMUtil read the file as mi./h and not as tenths of mi./h. Hence, the file read as mi./h was saved as a

text file in WDMUtil. The text file was opened in EXCEL. The values were converted to mi./d and the date field was modified to have four-digit years (mm/dd/yyyy); WDMUtil cannot read a date field with a two-digit year. The resulting file was saved as an ASCII flat file. A flat file cannot be created from the NCD file and considerable preprocessing is required if the WDMUtil is not used. The flat file was read back into WDMUtil to obtain DWND in mi/d. The DISAGGREGATE function in WDMUtil was used to obtain hourly wind speed (WIND) in mi/h.

4. <u>Total daily solar radiation (DSOL)</u>
   Solar radiation data is not collected at Dale Enterprise. Initially, it was proposed to use measured percent sun data for Elkins Airport (WV) to calculate DSOL; there were no other sites within a 100-mile radius of Dale Enterprise with solar radiation data. However, since DSOL record for Elkins Airport was only available until May 1994, synthetic DSOL was generated for Monterey, VA (Lat./ Long. 38.4N/79.6W, elevation 2950 ft) using CLIGEN in the WEPP input format. The resulting file was processed in EXCEL to obtain a text file with one column of days and another column of total daily solar radiation (ly) and with a date field with four-digit years. The modified DSOL text file was successfully read into WDMUtil. The DISAGGREGATE function in WDMUtil was used to obtain hourly solar radiation (SOLR).

5. <u>Percent sun (PSUN)</u>
   In the absence of daily cloud cover (DCLO), PSUN can be used to estimate DCLO. DCLO in turn is used by WDMUtil to estimate hourly cloud cover (CLOU) in tenths. An extensive search of the NCDC archive for locations as far away as Beltsville, MD (about 118 mi from DE) failed to provide DCLO, PSUN, or CLOU data more recent than July 1996. Hence, it was decided to use data for the period September 1984 through July 1996 from Lynchburg Airport in the following order of preference – CLOU, DCLO, and PSUN. Since CLOU was unavailable and DCLOU data had missing records, PSUN in the variable length format, obtained from the NCDC was used. The first four columns in each line of the PSUN file were deleted in a text editor and the resulting file was saved as an NCD file.

   A new WDM file was created and the PSUN NCD file was read into it. The COMPUTE function in WDMUtil was used to calculate DCLO (in percent) from PSUN. The resulting DCLO file was saved as a text file. The DCLO text file was opened in EXCEL and the date field was formatted (mm/dd/yy) and the DCLO value was converted from percent to tenths (e.g., 50% ≡ 5). The text file was further modified in a text editor to create a four-digit year field. The final DCLO flat file was read into WDMUtil. The final WDM file that contains all hourly and daily data does not contain PSUN. The DISAGGREGATE function used for disaggregating DWND to WIND was used to disaggregate DCLO into CLOU with all hourly coefficients being set equal to one. The choice of one as the coefficient for all hours in a day resulted in all CLOU values for a day being equal to DCLO value for that day. No separate DISAGGREGATE function is available for CLOU as there are for ATEM, DEWP, SOLR, WIND, and daily potential evapotranspiration (PEVT).

Input data and processing in WDMUtil required for HSPF input parameters

The input data and WDMUtil processing required for calculating hourly weather data required for use in HSPF are discussed above. Other parameters such as hourly Penman pan (potential) evaporation (EVAP) and hourly potential evapotranspiration (PEVT) require more than one type of input data. Table A.2 summarizes all the parameters that are required in modeling in HSPF as well as the inputs and methods required for calculating the parameters.

Table A.2. Weather parameters and processing in WDMUtil required for HSPF modeling

Input parameters	WDMUtil functions	HSPF parameter
PREC	No further processing required	PREC
TMAX and TMIN	DISAGGREGATE	ATEM
DPTP	DISAGGREGATE	DEWP
DSOL	DISAGGREGATE	SOLR
DWND	COMPUTE	WIND
TMAX and TMIN DEVT	COMPUTE DISAGGREGATE	DEVT (Hamon)[a] PEVT
TMAX, TMIN, DPTP, DWND, DSOL DEVP	COMPUTE DISAGGREGATE[b]	DEVP (Penman)[a] EVAP
PSUN DCLOU	COMPUTE DISAGGREGATE[c]	DCLOU[a] CLOU

[a] Parameters not required by HSPF

[b] DISAGGREGATE function for DEVT used

[c] DISAGGREGATE function for DWND used

[1]CLIGEN – Climatic Generator, a program used to generate weather parameters using historic data

APPENDIX C

Die-off of Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in different types of waste applied to cropland and pasture. All calculations were performed on spreadsheet (one for each subwatershed).

1. Fifty percent dairy farms have liquid manure storage for 90 days while 20% have 180-day storage capacity (VADCR, 1999). The remaining dairy farms have bedding storage capacity of 120 days (VADCR, 1999). Using decay rates of 0.375 and 0.05 (Table 5.2) for liquid and bedding storages, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all liquid dairy manure that also included bedding storage.

   Virginia DCR (1999) reported that the average storage capacity for both solid manure and poultry litter was 120 days. Hence, fecal coliform die-off values in solid manure and poultry litter storages at the end of 120 days were calculated using decay rates of 0.05 (solid manure) and 0.08 (poultry litter) (Table 5.2).

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of the storage periods described above was estimated separately for liquid manure, solid manure, and poultry litter. The surviving fractions of fecal coliform in liquid manure, solid manure, and poultry litter were 0.0624, 0.1621, and 0.1000, respectively.

3. The annual production of fecal coliform based on 'as-excreted' values (Table 3.3) was calculated separately for liquid manure, solid manure, and poultry litter. For poultry litter, the fecal coliform produced per annum was based on the relative contributions of layers, broilers, and turkeys.

4. The annual fecal coliform production from a source (e.g., liquid manure) was multiplied by the fraction of surviving fecal coliform in that source to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of waste applied during that month based on the application schedule given in Table 4.7.

APPENDIX D

Fecal Coliform Loading in Subwatersheds of lower Dry River

Table D.1. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-A of the lower Dry River watershed

Month	Fecal coliform loadings (´ 10^9 cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-Stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	93,143	38,191	220,239	9,251	9,251	0	2,767	965
Feb.	57,420	87,134	36,527	208,336	8,654	8,654	0	2,588	903
Mar.	287,102	175,891	76,161	427,818	9,251	9,251	0	6,640	739
Apr.	229,681	181,152	77,523	437,989	8,953	8,953	0	7,497	715
May	57,420	186,987	77,520	444,882	9,251	9,251	0	7,747	739
Jun.	0	255,173	77,616	437,093	8,953	8,953	0	7,497	278
Jul.	0	253,451	80,080	451,308	9,251	9,251	0	7,747	287
Aug.	0	257,315	80,080	451,308	9,251	9,251	0	7,747	287
Sep.	0	327,099	81,632	449,611	8,953	8,953	0	7,497	934
Oct.	85,028	187,190	78,402	447,669	9,251	9,251	0	7,747	965
Nov.	87,401	170,217	71,436	407,471	8,953	8,953	0	6,426	934
Dec.	0	93,143	38,191	220,239	9,251	9,251	0	2,767	965
Total	804,052	2,267,895	813,359	4,603,963	109,223	109,223	0	74,667	8,711

Table D.2. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-B of the lower Dry River watershed

Month	Fecal coliform loadings (´ 10^9 cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	97,869	15,649	384,134	7,272	7,272	0	24,862	104
Feb.	64,702	91,555	14,823	361,606	6,803	6,803	0	23,258	98
Mar.	323,512	184,453	30,429	735,888	7,272	7,272	0	59,668	104
Apr.	258,810	189,664	31,081	754,146	7,038	7,038	0	67,368	101
May	64,702	195,275	31,427	769,422	7,272	7,272	0	69,613	104
Jun.	0	272,569	31,496	752,489	7,038	7,038	0	67,368	101
Jul.	0	266,413	32,490	776,876	7,272	7,272	0	69,613	104
Aug.	0	272,595	32,490	776,876	7,272	7,272	0	69,613	104
Sep.	0	355,482	33,638	784,194	7,038	7,038	0	67,368	101
Oct.	94,688	195,986	31,725	774,472	7,272	7,272	0	69,613	104
Nov.	98,485	178,503	28,927	705,747	7,038	7,038	0	57,744	101
Dec.	0	97,869	15,649	384,134	7,272	7,272	0	24,862	104
Total	904,899	2,398,233	329,824	7,959,984	85,859	85,859	0	670,950	1,230

Table D.3. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-C of the lower Dry River watershed

Month	Fecal coliform loadings (´ 10^9 cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	108,694	17,773	164,665	6,227	6,227	0	8,300	248
Feb.	37,027	101,682	16,832	154,993	5,825	5,825	0	7,765	232
Mar.	185,133	206,044	34,728	317,047	6,227	6,227	0	19,921	248
Apr.	148,106	212,585	35,594	326,020	6,026	6,026	0	22,491	240
May	37,027	219,671	36,137	333,906	6,227	6,227	0	23,241	248
Jun.	0	261,936	36,744	331,349	6,026	6,026	0	22,491	240
Jul.	0	262,068	37,903	342,090	6,227	6,227	0	23,241	248
Aug.	0	265,545	37,903	342,090	6,227	6,227	0	23,241	248
Sep.	0	307,810	38,715	340,485	6,026	6,026	0	22,491	240
Oct.	54,223	219,671	36,342	334,857	6,227	6,227	0	23,241	248
Nov.	56,359	199,398	33,025	304,119	6,026	6,026	0	19,278	240
Dec.	0	108,694	17,773	164,665	6,227	6,227	0	8,300	248
Total	517,875	2,473,798	379,469	3,456,286	73,518	73,518	0	224,001	2,928

Table D.4. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-D of the lower Dry River watershed

Month	Fecal coliform loadings ($\times 10^9$ cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	81,794	11,367	41,764	7,105	7,105	0	5,534	64
Feb.	29,212	76,517	10,862	39,489	6,646	6,646	0	5,177	60
Mar.	146,059	153,155	22,438	80,366	7,105	7,105	0	13,280	64
Apr.	116,847	157,061	22,753	81,948	6,875	6,875	0	14,994	62
May	29,212	161,880	22,739	83,151	7,105	7,105	0	15,494	64
Jun.	0	192,780	22,217	80,445	6,875	6,875	0	14,994	62
Jul.	0	194,857	22,935	83,086	7,105	7,105	0	15,494	64
Aug.	0	196,403	22,935	83,086	7,105	7,105	0	15,494	64
Sep.	0	230,586	23,098	82,478	6,875	6,875	0	14,994	62
Oct.	43,515	162,297	23,025	83,784	7,105	7,105	0	15,494	64
Nov.	44,464	148,215	21,066	76,583	6,875	6,875	0	12,852	62
Dec.	0	81,794	11,367	41,764	7,105	7,105	0	5,534	64
Total	409,309	1,837,339	236,802	857,944	83,881	83,881	0	149,335	756

Table D.5. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-E of the lower Dry River watershed

Month	Fecal coliform loadings (´ 10^9 cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	26,579	21,054	49,131	2,092	2,092	0	0	239
Feb.	22,136	24,864	20,745	47,187	1,957	1,957	0	0	224
Mar.	110,680	48,663	43,826	96,190	2,092	2,092	0	0	239
Apr.	88,544	49,419	43,378	96,371	2,024	2,024	0	0	232
May	22,136	51,023	41,500	95,662	2,092	2,092	0	0	239
Jun.	0	77,408	40,914	93,300	2,024	2,024	0	0	232
Jul.	0	77,503	42,215	96,336	2,092	2,092	0	0	239
Aug.	0	78,275	42,215	96,336	2,092	2,092	0	0	239
Sep.	0	105,000	42,949	95,831	2,024	2,024	0	0	232
Oct.	33,219	51,066	42,584	96,968	2,092	2,092	0	0	239
Nov.	33,694	47,093	39,433	89,608	2,024	2,024	0	0	232
Dec.	0	26,579	21,054	49,131	2,092	2,092	0	0	239
Total	310,409	663,472	441,867	1,002,051	24,697	24,697	0	0	2,825

Table D.6. Monthly nonpoint fecal coliform loadings to the different land-use categories in the subwatershed DRR-F of the lower Dry River watershed

Month	Fecal coliform loadings (´ 10^9 cfu/month)								
	Crop-land	Pasture 1	Pasture 2	Pasture 3	Rural Resid-ential	Farm-stead	Urban Resid-ential	Loafing lot	Forest
Jan.	0	15,689	6,542	9,118	10,890	10,890	0	0	829
Feb.	18,746	14,677	6,960	9,117	10,188	10,188	0	0	775
Mar.	93,730	26,071	15,088	18,119	10,890	10,890	0	0	829
Apr.	74,984	25,230	13,897	17,043	10,539	10,539	0	0	802
May	18,746	26,071	11,728	15,773	10,890	10,890	0	0	829
Jun.	0	48,455	11,658	15,479	10,539	10,539	0	0	802
Jul.	0	49,296	12,009	15,969	10,890	10,890	0	0	829
Aug.	0	49,296	12,009	15,969	10,890	10,890	0	0	829
Sep.	0	71,680	12,779	16,262	10,539	10,539	0	0	802
Oct.	28,534	26,071	12,568	16,359	10,890	10,890	0	0	829
Nov.	28,534	25,230	12,217	15,869	10,539	10,539	0	0	802
Dec.	0	15,689	6,542	9,118	10,890	10,890	0	0	829
Total	263,274	393,455	133,997	174,195	128,574	128,574	0	0	9,786

APPENDIX E

Required Reductions in Fecal Coliform Loads by Subwatershed – Allocation Scenario

Table E.1a. Required annual reductions in nonpoint sources in subwatershed A (drainage area of Dry River below the confluence of Dry River and Muddy Creek)

Land-use	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cropland	13,100	23.8	13,100	0
Pasture 1	14,700	26.8	14,700	0
Pasture 2	1,120	2.0	1,120	0
Pasture 3	25,100	45.7	25,100	0
Rural Residential	271	0.5	271	0
Farmstead	560	1.0	560	0
Urban Residential	1	0.0	1	0
Loafing lot	51	0.1	51	0
Forest	29	0.1	29	0
Total	54,932	100.0	54,932	0

Table E.1b. Required annual reductions in direct nonpoint sources in subwatershed A (drainage area of Dry River below the confluence of Dry River and Muddy Creek)

Source	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL direct nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cattle in streams	26,742	93.1	4,279	84
Wildlife in streams	1,984	6.9	1,984	0
Milking parlor wash-off	0	0.0	0	0
Total	28,726	100.0	6,263	78.2

Table E.2a. Required annual reductions in nonpoint sources in subwatersheds B, D, and E (drainage area of Honey Run)

Land-use	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cropland	41,000	21.5	41,000	0
Pasture 1	59,100	31.0	59,100	0
Pasture 2	10,900	5.7	10,900	0
Pasture 3	76,100	39.9	76,100	0
Rural Residential	479	0.3	479	0
Farmstead	988	0.5	988	0
Urban Residential	2	0.0	2	0
Loafing lot	1,870	1.0	1,870	0
Forest	244	0.1	244	0
Total	190,683	100.0	190,683	0

Table E.2b. Required annual reductions in direct nonpoint sources in subwatersheds B, D, and E (drainage area of Honey Run)

Source	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL direct nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cattle in streams	155,635	99.2	24,902	84.0
Wildlife in streams	156	0.1	156	0.0
Milking parlor wash-off	1,048	0.7	0	100.0
Total	156,839	100.0	25,058	84.0

Table E.3a. Required annual reductions in nonpoint sources in subwatersheds C and F (drainage area of Dry River above the confluence of Dry River and Muddy Creek)

Land-use	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cropland	13,400	15.2	13,400	0
Pasture 1	46,100	52.4	46,100	0
Pasture 2	2,690	3.1	2,690	0
Pasture 3	10,500	11.9	10,500	0
Rural Residential	4,520	5.1	4,520	0
Farmstead	7,010	8.0	7,010	0
Urban Residential	2	0.0	2	0
Loafing lot	193	0.2	193	0
Forest	3,600	4.1	3,600	0
Total	88,015	100.0	88,015	0

Table E.3b. Required annual reductions in direct nonpoint sources in subwatersheds C and F (drainage area of Dry River above the confluence of Dry River and Muddy Creek)

Source	Existing conditions load (´ 10^9 cfu)	Percent of total load from direct nonpoint sources	TMDL direct nonpoint source allocation load (´ 10^9 cfu)	Percentage reduction
Cattle in streams	0	0.0	0	0.0
Wildlife in streams	218	100.0	218	0.0
Milking parlor wash-off	0	0.0	0	0.0
Total	218	100.0	218	0.0

APPENDIX F

Explanation of Dry River Flow Distribution

Explanation of Dry River Flow Distribution

The distribution of flow among surface runoff, interflow, and ground water by subwatershed for the Dry River simulations is listed in Table 1a for pervious land segments. The combined flow totals from both pervious and impervious areas are presented in Table 1b. The small portion of flow contributed from surface flow and large portion from ground water is a direct result of the INFILT values used in the model. The INFILT values used in the Dry River simulations were derived from soil characteristics and qualitative information provided by local residents. The general method used was to determine the hydrologic soil group for each sub watershed and then use the ranges for INFILT listed for each hydrologic soil group in EPA Tech Note 6 (page 4). The higher end of each range was selected based on observations of local residents that surface runoff (water ponded on the ground surface) rarely occurred during rainfall events. In the following paragraphs, the specific procedures used to derive the INFILT values are discussed.

Table 1a. Distribution of Flow Among Surface Runoff (SURO), Interflow (IFWO), and Base Flow (AGWO) for Lower Dry River and subwatersheds (pervious land segments only).

Wtsd	SURO	IFWO	AGWO
001	4.72%	36.30%	58.98%
002	4.72%	36.30%	58.98%
003	0.30%	7.17%	92.52%
004	0.32%	7.33%	92.35%
005	0.32%	7.33%	92.35%
006	0.32%	7.33%	92.35%
Total	**1.94%**	**18.01%**	**80.05%**

Table 1b. Distribution of Flow Among Surface Runoff (SURO), Interflow (IFWO), and Base Flow (AGWO) for Lower Dry River and subwatersheds (pervious and impervious land segments combined).

Wtsd	SURO	IFWO	AGWO
001	8.41%	34.89%	56.70%
002	7.37%	35.29%	57.34%
003	4.28%	6.89%	88.83%
004	3.75%	7.08%	89.17%
005	3.05%	7.13%	89.81%
006	3.92%	7.07%	89.01%
Total	5.31%	17.39%	77.29%

The main data resource used to select the INFILT values for the Dry River simulations was the Rockingham County, VA Soil Map (in digital form from SURGO). The hydrologic groups of the soils occurring within the watershed boundaries are shown in Figure 1

(Note: the subwatershed numbers in the figure correspond to the number listed in Table 1a and 1b). Most of the soils in subwatersheds 003 through 006 are classified as hydrologic group B (moderate runoff potential). In subwatersheds 001 and 002, most soils are classified as hydrologic soil group C (moderate to high runoff potential). The area-weighted hydrologic soil group was calculated for each subwatershed in order to determine the average conditions for each subwatershed.

Once the hydrologic soil groups were determined for each subwatershed, the INFILT value for each subwatershed was determined. The Hydrologic Soil Groups for each subwatershed are listed in Table 2 and shown in Figure 2. Subwatersheds 003 through 006 had a moderate runoff potential (Hydrologic Soil Group B) and subwatersheds 001 and 002 had a moderate to high runoff potential (Hydrologic Soil Group C). Based on the observations of local residents that water rarely ponds on the ground surface during rainfall events, it was decided that the high end of the range should be selected as the INFILT value used for the subwatershed. The INFLT values used in the simulations for Dry River are listed in Table 2.

Table 2. Hydrologic Soil Groups and INFILT Values for each Subwatershed.

Wtsd	Hydrologic Soil Group	INFILT
001	C	0.1
002	C	0.1
003	B	0.4
004	B	0.4
005	B	0.4
006	B	0.4

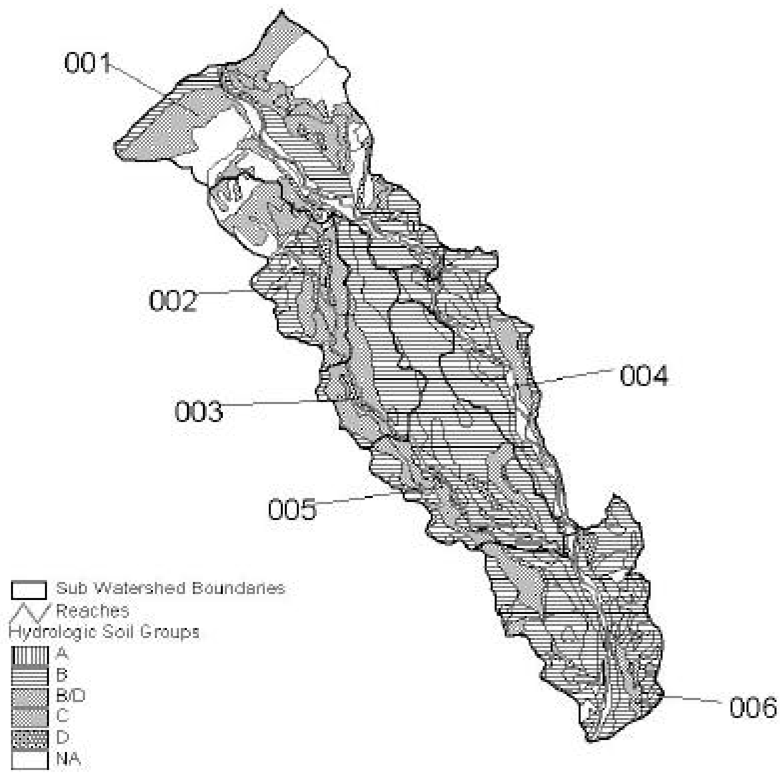

Figure 1. Distribution of Hydrologic Soil Groups of Soil in the Dry River Watershed.

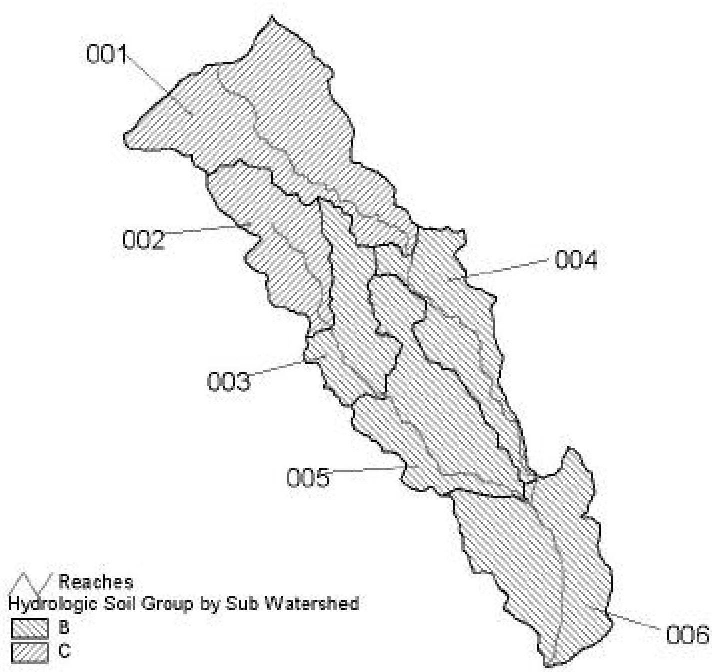

Figure 2. Hydrologic Soil Groups of the Dry River Subwatersheds.

ADDENDUM

- Response to EPA Comments -

September 2000

Summary of Changes to the Mill Creek, Pleasant Run and Dry River TMDL Reports for September 2000

On May 1, 2000, the Commonwealth submitted to the US Environmental Protection Agency (EPA) the fecal coliform TMDLs developed for Mill Creek, Pleasant Run and Dry River in Rockingham County, Virginia. These TMDLs, together with eight others, were subsequently retracted due to a number of concerns raised by EPA (e-mails dated 3/11/00 and April 2000, letter dated 5/18/00). The Commonwealth has incorporated modifications to the TMDLs that resulted from communications with EPA. This document outlines the alterations and additions for each TMDL report.

For the Mill Creek TMDL, two HSPF calibration parameters (INTFW and INFILT) were changed in order to improve flow partitioning in the hydrology calibration. To reflect this, a paragraph describing the parameter values for INTFW and INFILT was inserted on page 57 of the report. On the same page, the resulting flow partitioning values were added. Two more HSPF parameters, AOQC and IOQC, were modified to reflect more reasonable fecal coliform concentrations in groundwater and interflow. The IOQC and AOQC values in table 5.10 were changed accordingly.

The parameter changes resulted in slightly different loads and concentrations, and consequently in a small increase of the wildlife reduction (70% instead of 60%). Tables 1.1 through 1.4, 6.1 through 6.5, 7.1 through 7.3 as well as all tables in Appendix E were modified with the concentrations, loads and percent reduction resulting from the new parameters. Figures 1.1, 5.4, 5.5, 6.1, 6.2, and 7.1 were replaced by the new model plots. Also, the corresponding text passages were revised.

Additionally, table 3.4 and figure 3.6 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively.

For the Pleasant Run TMDL, a sentence describing flow partitioning was added on page 56. Table 5.10 was changed to reflect changed values for IOQC and AOQC, which resulted in slightly different loads and concentrations, and consequently in a small increase of the wildlife reduction (15% instead of 10%). This increase did not result in any changes to tables 1.2 and 1.4, 6.1, 6.3 or 6.5, 7.1 through 7.3 or to the tables in Appendix E. However, tables 1.1, 1.3, 6.2 and 6.4 were modified with the percent reduction resulting from the new parameters. Figures 1.1, 6.1, and 7.1 were replaced with the new model plots. Also, the corresponding text passages were revised. Table 3.4 and figure 3.6 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively

For the Dry River TMDL, a sentence describing flow partitioning was added on page 64. INTFW and INFILT were the not changed, but a justification for these values was added as Appendix F. Table 5.10 was modified to reflect changed values for IOQC and AOQC. These changed values did not result in any changes to the concentrations, loads and percent reduction in tables 1.1 through 1.4, 6.1 through 6.5, 7.1 through 7.3 or to the tables in Appendix E. Also, the original figures 1.1, 5.4, 5.5, 6.1, 6.2, and 7.1 were retained. Table 3.4 and figure 3.3 showing average monthly flows were inserted in chapter 3.6.1. Two paragraphs (from e-mail dated 5/22/00) regarding storage issues and manure application were incorporated in chapters 5.4.2 and 5.4.3 respectively.

Individual Changes to the Dry River Report

- **Page 22 -** Table 3.4 was added
- **Page 23 -** Figure 3.3 was added
- **Section 5.4.2** (page 52) – the following was added "The method used to calculate the fraction of fecal coliform surviving in the manure at the end of storage considered the duration of storage, type of storage, type of manure, and die-off factor. When calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land was estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month."
- **Section 5.4.3** (page 52) – the following was added "Total manure production was calculated using animal population and waste produced per day per animal. Animal numbers for the watershed were supplied by VADCR. These numbers were further refined by consulting with producers and Virginia Cooperative Extension faculty located in that county. The refined animal numbers were also checked against pasture acreage (for beef) and housing capacity (for poultry) to ensure that the estimates were reasonable. For dairy cattle population, the number of dairies in each subwatershed and the number of dairy cattle in each dairy farm were estimated in consultation with producers. The numbers on daily waste production from different animal species were obtained from published sources such as the ASAE Standards or Virginia Nutrient Management Standards Criteria. Estimation of manure produced in different locations (e.g., confinement, pastures) were based on guidelines provided by VADCR which were confirmed or modified through discussion with producers and extension personnel."
- **Page 64 -** The following sentence was added. "Detailed information justifying the INTFW and INFILT values used in the Dry River TMDL is included in Appendix F."
- **Page 64 -** The following sentence was added. "Partitioning of the total flow indicated that surface flow (SURO), interflow (IFWO), and active groundwater (AGWO) accounted for 5.31%, 17.39%, and 77.29% of the flow, respectively."
- **Page 68 –** Table 5.10. IOQC and AOQC values were changed
- **Appendices** - Appendix F was added